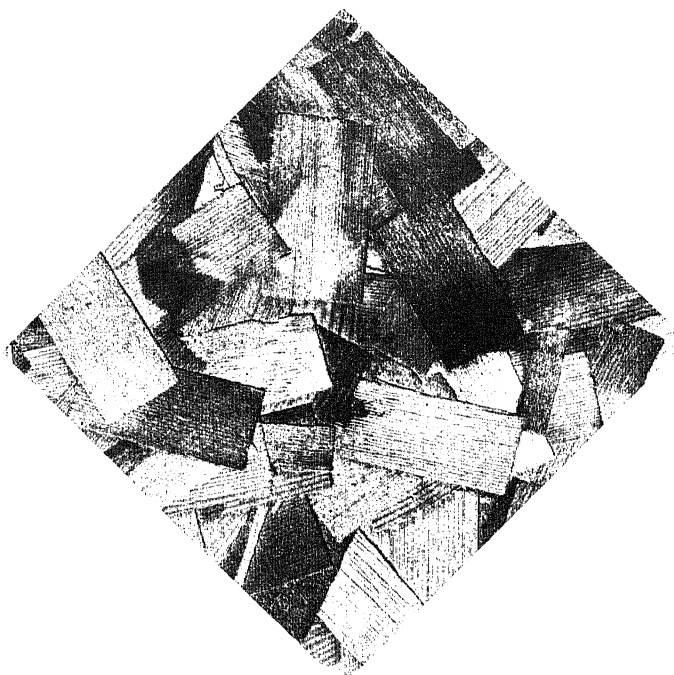A 13.88:WO-5

STRUCTURAL FLAKEBOARD

STRUCTURAL FLAKEBOARD

FROM FOREST RESIDUES

FROM FOREST RESIDUES

U.S. Department of Agriculture
Forest Service
General Technical Report WO-

STRUCTURAL FLAKEBOARD FROM FOREST RESIDUES

PROCEEDINGS OF A SYMPOSIUM
PRESENTED BY THE
USDA FOREST SERVICE
JUNE 6-8, 1978
KANSAS CITY, MO,

GENERAL TECHNICAL REPORT WO-5
FOREST SERVICE
U.S, DEPARTMENT OF AGRICULTURE
WASHINGTON, D,C,

September 1978

Timber stands often contain large volumes of materials that are uneconomic to process into lumber and plywood. These may be the residue left in the forest after harvesting, the mill residue resulting from the processing of the timber, or whole stands of traditionally unharvested species.

For this reason, the Forest Service of the U.S. Department of Agriculture initiated a major research program in the early 1970's directed to the development of technologies for using forest-residue-type materials for the manufacture of structural flakeboard. Overall objectives of this research were to develop and demonstrate the technical and economic feasibility of manufacturing structural sheathing products from forest residues. To accomplish these objectives, facts were needed about forest residues, harvesting, and flaking, about structural flakeboard manufacture and strength properties, and about the economic opportunities for commercialization of structural flakeboard production from forest residues.

Because of the complexity and interrelated characteristics of research requirements, a Forest Service Structural Flakeboard Task Force was appointed in

1973 by the Chief of the Forest Service, John R. McGuire. Under the direction of the Deputy Chief for Research, Robert E. Buckman, this task force has provided the leadership in coordinating this Forest Service-wide program of research.

When the planned objectives of the Task Force had been met, the research results were brought together in a symposium held in Kansas City, Mo., June 6-8, 1978. The symposium was conducted through the efforts of the Forest Products Research Society. This report is a compendium of the research accomplishments presented at the symposium. Although this report deals with the subject of utilizing forest residues for manufacture of structural flakeboard products, it also contains a wealth of technical information and analytic methodology of value to those interested in other aspects of flakeboard manufacture and residue utilization.

Special acknowledgments are due to Columbia Engineering International, Ltd., to the Forest Products Research Society, Madison, Wis., and to the many research personnel who have participated in this program, including the authors of the following summaries of studies.

FOREST SERVICE STRUCTURAL FLAKEBOARD TASK FORCE

ROBERT L. ETHINGTON, Director, Forest Products and Engineering Research, Washington, D.C.

DEAN N. QUINNEY, Deputy Director, Forest Resources Economics Research, Washington, D.C.

HOWARD T. TAYLOR, Assistant Director, Forest Service Engineering, Washington, D.C.

THADDEUS A. HARRINGTON, Assistant Director, Southern Forest Experiment Station, New Orleans, La.

ALAN D. FREAS, Assistant Director, Forest Products Laboratory, Madison, Wis. Retired.

BILLY BOHANNAN, Assistant Director, Forest Products Laboratory, Madison, Wis.

JOHN I. ZERBE, Energy Research, Development, and Application, Forest Products Laboratory, Madison, Wis.

DONALD F. FLORA, Assistant Director, Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.

CON H. SCHALLAU, Research Economist, Pacific Northwest Forest and Range Experiment Station, Corvallis, Oreg.

ROLAND L. BARGER, Forest Residues Research, Development, and Applications, Intermountain Forest and Range Experiment Station, Missoula, Mont.

VERNON W. MEYER, State and Private Forestry, Northern Region, Missoula, Mont.

and

CHARLES R. MORSCHAUSER, Technical Director, National Particleboard Association, Silver Spring, Md.

TABLE OF CONTENTS

INTRODUCTION

INTRODUCTION TO
THE STRUCTURAL FLAKEBOARD FROM FOREST RESIDUES SYMPOSIUM

Robert E. Buckman
Associate Deputy for Research
USDA Forest Service
Washington, D.C.

It is my pleasure to welcome you to this symposium to discuss the wrap-up of the Forest Service program on structural flakeboard from forest residues. A real benefit of this symposium is the fact that we have most of the principal scientists involved in the research with us today. Even though each of you has been given a copy of the Proceedings of this symposium, the added feature of having these scientists with us is that they will be able to supplement their papers in the Proceedings and to answer any specific questions you might have pertaining to their area of research.

The fact that we are here today is the culmination of over five years of research effort by USDA Forest Service research scientists. These scientists benefitted from the results of research conducted during the past two decades by university and industrial laboratories. They also cooperated with our National Forest System, with assistance from our State and Private Forestry Branch. In fact, one of the papers being presented today is by Dr. Richard Jorgensen, who is our national wood construction specialist in State and Private Forestry. In addition to this, we have Peter Vajda, a consultant in plant and facilities, and Richard Withycombe from the University of Montana. We must also pay tribute to Charles Morschauser of the National Particleboard Association, who offered advice and counsel throughout the program.

This whole effort began approximately six years ago when, in June of 1972, Chief John McGuire approved the Close Timber Utilization Report and committed the Forest Service to a Service-wide, five-year effort to reduce all residues on Forest Service lands. Forest residues appear in many forms. They may be dead or dying trees and cull trees. They may be trees too small to be considered merchantable by commercial standards, or trees or species which have no marketable value can be considered residues. Timber harvest results in accumulations of logging slash which can most definitely be classified as residues.

Regardless of the source of the residues, the primary purpose behind the Forest Service commitment was the need for research to upgrade the quality of environmental management and to extend timber supplies through improved treatment of forest residues whether they be logging residues or other. Many opportunities for utilizing residues were discussed, but it became apparent that structural flakeboard was the best possibility for consuming large quantities of residues as a substitute for lumber and plywood products from roundwood. So the objective to develop an economical panel product from flaked residues competitive in function and price with sheathing grade plywood was set.

A program evaluation review technique or PERT charted plan for accomplishing the objective was developed. The PERT chart plan is realistic but it is also flexible. Not too much flexibility was required. Most of the objectives or events of the plan were met on schedule. The first task defined on the chart was the establishment of performance goals for the structural flakeboard we were to develop. These goals were established in about a month by an ad hoc work group under the leadership of Con Schallau. In developing the goals for structural flakeboard, the properties of sheathing grade plywood, tempered by realistic expectations and reasonable performance requirements, were determining factors. The goals were merely meant to be targets to strive for, and were not necessarily recommendations for eventual product specifications.

Flakeboards were developed at the Forest Products Laboratory in Madison, Wisconsin, and the Southern Experiment Station's Forestry Center at Alexandria, Louisiana. Research aimed at harvesting the raw material or collecting and transporting it, and breaking it down into material for the flaker, was conducted in Houghton, Michigan; Missoula, Montana; and Alexandria, Louisiana. An important part of the program was the economic and marketing assessment of structural flakeboard. I am sure you have all noticed that a good share of this week's program is devoted to the opportunities for establishing structural flakeboard plants throughout the United States.

One of the final events of our PERT chart was the transfer of the technology developed during our program. This, of course, is why we are here today. We feel we have a good story to tell and are proud to share it with you.

This program is an excellent example of the cooperation between the branches of the Forest Service, and with the assistance of industry advisors. This spirit of cooperation is being carried

one step further in the presentation of
this symposium. The USDA Forest Service
and the Forest Products Research Society
are cooperating in it's presentation. We
were very fortunate to be able to have
a co-sponsor such as FPRS helping us. It
freed us of the details of site location
and selection and proceedings preparation
and permitted us to direct all of our
efforts toward giving you a good program.
So with this short introduction and wel-
come, I will yield the podium to Thad
Harrington, who will introduce the first
topic and speakers of the seminar. I
hope you have an enjoyable and fruitful
session.

FACTORS INFLUENCING MARKET POTENTIAL FOR STRUCTURAL FLAKEBOARD

H. Edward Dickerhoof
Industry Economist

Thomas C. Marcin
Economist

Forest Products Laboratory
USDA Forest Service
Madison, Wisconsin

Abstract

The primary market opportunities for structural flakeboard are in new residential construction. Recently developed Forest Service projections show continued strong demand for single- and multi-family housing during the next five years. This increased housing demand will result in expanded markets for floor decking and wall and roof sheathing. A major factor influencing the market success of structural flakeboard in these markets will be its cost in relation to other competing board products--particularly softwood plywood. Although structural flakeboard may offer several favorable technical characteristics, it should also be competitive in price in order to penetrate most board markets.

Introduction

The success of structural flakeboard manufacture in the United States will depend on several interrelated factors such as market demand, competition from other domestic and foreign board manufacturers, building code acceptance, and the physical characteristics of the product. This paper will briefly discuss how these and other factors may influence the market potential for structural flakeboard.

Major Markets

The major markets for structural flakeboard include: 1) new residential construction-- single-family, multi-family, and mobile homes; 2) nonresidential construction--agricultural buildings, public, commercial, and industrial buildings, concrete forms, and others; 3) industrial uses--containers and pallets; and 4) residential remodeling and repair. While all of these offer great potential for structural flakeboard, the size and complexity of each market is too large to cover in one paper. Therefore, we will concentrate on the new residential construction market.

*Numbers in parentheses refer to References at the end of each article.

-----

[1]Does not include prefabricated or modular homes.

U.S. Housing Demand

New residential housing demand will be a major factor in the degree of success structural flakeboard will enjoy in the U.S. market. Although other construction markets may be attractive and offer good opportunities, the new residential housing market must be given serious consideration.

In looking back five years, it is easy to see that the housing market has been highly variable (Table 1). Fortunes are quickly made in this market and, as we saw in the 1975 recession, they are easily lost.

Construction of single-family homes, the largest segment of the market, has not only recovered from recession levels, but in 1977 advanced beyond the 1973 level. Single-family home construction in 1977 was near an all-time record of approximately 1.5 million starts (5).*

Private and public multi-family housing starts in 1973 totaled 924,000 units, just slightly below the record 1.1 million units built the previous year (8). But by 1975, multi-family starts plummeted to 276,000 starts, recovering to 538,000 units in 1977 (8).

Mobile home shipments,[1] the glamour segment of the housing industry in the early 1970's, were at 567,000 units in 1973 (8). By 1975, shipments had slid to 213,000 units, causing the closing of hundreds of mobile home plants. The mobile home industry has lagged behind the rest of the housing industry in its recovery, producing only about 277,000 units in 1977 (8). But this recovery may be better than these figures alone suggest, because many mobile home plants are now producing modular homes as well as mobile homes. Also, mobile homes are becoming larger. Single-wides are on the average becoming larger each year with 14-foot-wides now being built in almost every state. About 30 percent of all units are double-wides, which are actually houses--both in terms of construction and appearance.

Projections of new residential housing demand from 1978 to 2020 have just been published by Marcin (4). These projections show a continued strong demand for new housing during the next five years followed by a slight decline in 1984 and then a return to construction activity approximately at or slightly better than the levels posted in 1977 (Table 2). These

3

projections are a measure of potential housing demand and are not forecasts of actual housing starts. They are based upon yearly projections of population by age group and certain assumptions about future economic growth. The population projection series are made by the U.S. Census Bureau. To generalize, it is assumed that the two-child family will prevail in the future and that people continue to follow historical patterns of moving into single-family homes as they reach middle age. Economic growth is assumed to continue at historic long-term trend rates.

The demand for single-family housing units is projected to be very strong for the 10-year period, 1978-1987. Approximately 63 percent of all units built during this period will be single-family units. Since single-family units traditionally require the largest amounts of plywood sheathing and sawn lumber materials per unit, this is a very favorable market factor.

Multi-family housing demand is projected to average 555,000 units per year for the period 1977-1987. This will be about 23 percent of all residential construction (Table 2). The apartment construction activity of about 1 million units per year that we experienced for three years in the early 1970's is not likely to reoccur. In fact, the projections to 2020 show that demand at approximately one-half million units per year can be expected as normal. Thus, this should not be considered as a growth market.

The Forest Service projections of mobile home manufacture are similar to those for apartments. Their demand is anticipated to average 353,000 units for the period 1977-1987. (Production may fluctuate more than conventionally built houses from year to year because this industry is more sensitive to business cycles and it can accumulate an inventory of houses.) This will only be about 14 percent of total residential construction. However, many companies now producing mobiles will also be manufacturing modulars to help meet the growing demand of single-family homes. Since mobile home manufacturers are quick to use new materials and techniques to cut their cost, they could be a good potential market for structural flakeboard.

Regional Housing Demand

Much of the anticipated housing demand during the next decade will be centered in the South where 42 percent of the projected starts will occur and the West where 25 percent will occur (Table 2). These are regions where our softwood forest resources and industry are also concentrated, but there should be good potential for forest industry in the other regions. The North Central Region will have about 20 percent of the total demand, while the Northeast will have the remaining 13 percent.

Housing Demand and Potential Market for Structural Flakeboard

The housing demand projections discussed above, when combined with floor decking and wall and roof sheathing use factors, can be used to estimate the potential size of the residential structural board and siding market. The U.S.

Forest Service has just completed a preliminary calculation of these factors by region for single family housing, multi-family housing, and mobile homes.

Our single- and multi-family structural board use estimates include floor decking and exterior wall and roof sheathing. These estimates are based on 1976 use and are weighted to take into account the different amounts of material used in attached single-family units (such as condominiums) and detached single-family units.

Our mobile home board projections are based on a Forest Service survey conducted in 1975-76 to determine quantities of wood materials used for floor and roof decking, wall sheathing, and siding. These preliminary projections are probably conservative due to the trend in the mobile home industry toward the construction of more double-wide units which use more wood wall and roof sheathing materials than single-wide mobile homes.

The projected average annual demand for floor decking and wall and roof sheathing in the United States is 6,610 MMSF, 1/2-inch basis (Table 3). Projections of siding use were not included although a surface finish can be applied to structural flakeboard for entry into this market. The total wood siding market is very difficult to project because of the many alternatives available from plywood, hardboard, and lumber, as well as from nonwood materials. However, if siding were included, the total projected U.S. market should be in the neighborhood of 7,500 MMSF, 1/2-inch basis.

Regional Board Product Potential

Among the regions, the largest market is the South (Table 3). However, the South is a large geographic area compared with the North Central and Northeastern Regions. An average single-family house in the South contains fewer wood panel products than houses elsewhere, because concrete slab floor systems and concrete block and stucco wall systems are popular in many of the large markets in the South, such as Florida and Texas.

In terms of wood use, houses in the Western Region of the United States also often have characteristics similar to those in the South. Large quantities of concrete products are used in many areas, especially in the heavily populated areas in California and Arizona.

In the North Central and Northeastern States, wood structural panel use per housing unit (especially single-family units) has been very high. Based on this past tradition, the projected use for these regions shows the North Central Region to be a very good potential market for a product like structural flakeboard. However, the trend in the last year in this area is toward the use of insulating foam wall sheathing in place of traditional wood sheathing products. While few data are yet available to document the size of this material use shift, on-site observations in new housing developments

suggest that the impact on markets for wood wall sheathing products could be considerable. Market inroads by foam wall sheathing could be even more significant if state and federal minimum insulation requirements now being considered are passed into law.

One of the standards now being considered is an R-19 value for walls. (For more complete information on how to calculate resistance to the flow of heat for various wall constructions, see "How to Figure Heat Loss and Fuel Cost" (7).) Builders using conventional wall stud spacing and wood sheathing materials can obtain R value ratings just under R-19 fairly easily. But to reach values a little higher with standard wood frame and wall systems is apparently rather difficult. Builders currently advertising voluntary compliance with this standard apparently find that the cheapest method of doing this is with some foam insulation board. Therefore, while the North Central and Northeastern housing markets currently look strong based on the intensive use of structural wood panel products per individual housing unit, our projections in Table 3 could be revised downward because of a potential switch to foam wall sheathing materials.

Canadian Experience

Waferboard is the term used by the Canadian government and industry to describe their exterior particleboard intended for exterior sheathing uses (2). Waferboard has been manufactured in Canada since the beginning of the late 1960's. A Canadian government study published in 1975 reported six plants either under construction or in production with an estimated 1976 annual capacity of about 450 MMSF, 1/2-inch basis. (Table 4) (2).

During all or most of 1977, the waferboard plant at Lesser Slave Lake was not in production. However, officials of the Canadian Department of Industry, Trade, and Commerce, in telephone conversations with the author, reported this plant is well maintained and capable of resuming production on short notice.

Statistics Canada reported that in 1976, 267 MMSF, 1/2-inch basis of phenolic-bonded particleboard was produced in Canada, of which 242 MMSF were shipped to both domestic and foreign markets (6). Canadian government sources unofficially estimate that about 50 percent of these shipments were to U.S. markets.

For 1977, Statistics Canada reported phenolic-bonded particleboard production was 307 MMSF, 1/2-inch basis, while shipments were 376 MMSF (6). It was unofficially estimated that about 55 percent of these shipments or about 180 MMSF were exported. These exports were most likely to U.S. markets.

Major Markets[2]

Waferboard in Canada is widely used in residential construction for sheathing applications. In single-family and low-rise multi-family

housing, it is frequently used for exterior wall and roof sheathing—generally replacing sheathing-grade plywood. Some waferboard is also replacing "soft" wood fiber insulation board which is currently used as sheathing. According to the Canadian Department of Industry, Trade, and Commerce, waferboard is not widely used for floor decking. Other related residential uses are for garden sheds and fencing privacy screens. Waferboard is also reported to be used in mobile and modular construction and in the construction of barns and other farm buildings.

Waferboard is also used in Canada for packaging and crating. This market could be very promising in the United States, especially in the shipment of agricultural products.

Pricing[2]

Waferboard in Canada is generally sold at prices less than or competitive with plywood which would be used for the same purpose. Because most of Canada's larger markets are in the East—particularly Quebec and Ontario—waferboard has a freight cost advantage over plywood which is produced mostly in British Columbia. Thus, the delivered cost of waferboard as compared with softwood plywood is considered to be a major factor influencing the popularity of waferboard in Canada

Convenience of Delivery[2]

Another factor favoring waferboard in Canada relative to softwood plywood is said to be rapid delivery from plant to construction site. Because of the close proximity of the waferboard plants to some of the major Canadian markets, overnight truck delivery is said to be possible.

U.S. Situation

Production

Waferboard has been commercially manufactured in the United States since the early 1970's by Blandin Wood Products Company of Grand Rapids, Minn. The annual capacity of this plant has been estimated over the years at several different quantities by the trade press; however, 1976 annual capacity was estimated at 49 MMSF, 1/2-inch basis (2).

Price Strategy

The question of how a new product should be priced is always near the top of the list of difficult decisions that must be made by corporate leaders. One of the better references on the subject that can be recommended is Dean's paper "Pricing Policies for New Products" (1). The article has been widely referenced as one of the best commentaries on this very complex subject. It was recently updated by Dr. Dean and republished as a Harvard Business Review Classic.

Dean points out that new products can often be priced high when they are first introduced to the market if they are distinctive from their

competition. However, as competing manufacturers enter the market, it is difficult to maintain the high initial price strategy. Furthermore, Dean states:

> The seller's zone of pricing discretion narrows as his distinctive "specialty" fades into a pedestrian "commodity" which is so little differentiated from other products that the seller has limited independence in pricing, even if rivals are few (1).

Thus it would appear from these statements and the Canadian experiences that structural flakeboard will have to be priced less than or competitive with softwood plywood (CDX) in order to penetrate the major residential housing markets. This, indeed, appears to be the current pricing situation for Canadian waferboard currently sold in the United States. However, there are no specific data available on waferboard price trends in the United States.

Softwood Plywood Prices

Since structural flakeboard will in all likelihood be competing with softwood plywood at least in part on the basis of price, it is appropriate to look briefly at plywood prices over the last 10 years. Prices of Douglas-fir plywood, 1/2-inch standard exterior (3-ply) 1,000 square feet, were quite variable during the 1967-1977 period—ranging from less than $60 in 1967 to about $240 this last year (Fig. 1). Thus, if structural flakeboard manufacturers must follow the plywood industry's price leadership, they should be ready to make rapid and frequent price adjustments and sell their product at relatively low prices over long periods of time. The periods of higher prices for plywood in the last 10 years have been relatively brief. Added structural board capacity in the United States may serve to dampen these wide price variations—especially upward movement during periods of strong demand over a relatively short time period. But this potential benefit would be difficult to predict at this time.

Building Codes

Dr. Jorgensen will provide us with the details on the status of code acceptance in the following paper. Without proper code approval or if the status of code approval is in a state of confusion, the product will be handicapped severely in the marketplace. Potential users will simply not take a chance on having problems.

Favorable Physical Characteristics

Structural flakeboard has characteristics that should help it compete favorably with softwood plywood. All structural flakeboard will have a solid surface. This should help it compete in the floor decking market. Its relative stiffness gives it a solid feel underfoot when used as floor decking. The flakes can also be aligned for added strength. Equipment can be specified to produce large panel sizes which would be highly desirable for mobile and modular home manufacturers. Finally, structural flakeboard is a "solid core" product. This should prove to be a good all-around advantage.

Individual Panel Weight

Structural flakeboard panels will tend to be heavier than their plywood competitors. Panels with large ratios of hardwood to softwood flakes will probably be noticeable to carpenters but not objectionable, since other panel materials such as interior dry-wall panels would be about the same weight.

Total panel weight would be more important when considering shipping weight and freight costs. The potential for freight costs above the costs incurred by competing panel products which would cover the same floor, wall, or roof area must be considered. The total delivered cost is the important cost to the consumer.

Summary and Conclusions

The projected strong demand for housing over the long run in the United States is an important and favorable factor for potential manufacturers of structural flakeboard. New single-family housing is projected to lead this demand trend which will provide a good opportunity for structural flakeboard to share in this large floor decking and sheathing market.

The South and West will be the regions where single-family housing starts will be largest and hence will provide the largest floor decking and sheathing market. However, the North Central states will also offer good market opportunities, perhaps as good as the southern and western regions considering the total size of each geographic area. An analysis of recent floor decking and sheathing use data shows that individual single-family housing units in the North Central and Northeast use much more of these materials per unit than in other regions. However, foam insulation sheathing materials are making a strong bid for the exterior wall sheathing markets in these northern regions.

Canada has been producing waferboard since the late 1960's. Estimated total Canadian capacity is estimated at about 450 MMSF, 1/2-inch basis. Most of this plant capacity is located in the Canadian Midwest relatively close to major Canadian and U.S. markets. Total Canadian shipments of waferboard in 1976 were 242 MMSF and in 1977, 326 MMSF, 1/2-inch basis. At least 50 percent of these shipments were to U.S. markets. Waferboard in Canada is widely used for wall and roof sheathing and to a lesser extent for floor decking in both single- and multi-family housing. It is generally priced to be competitive with softwood plywood.

The pricing strategy for structural flakeboard in the U.S. market will probably be to target prices less than or competitive with softwood plywood of similar grade. Thus production cost targets should be set as low as possible, taking into consideration the wide price variation of plywood over the past 10

years with long periods of relatively low prices.

Perhaps the overriding factor in favor of the development of a structural flakeboard industry in the United States is the favorable outlook for the housing industry. It is always much easier to launch a new product when the market is growing than when it is in a downturn period. Thus, the timing may be quite good to begin the development of the industry now.

References

1. Dean, Joel. 1976. Pricing policies for new products. Harvard Business Review. 54(6): 141-153.

2. Canadian Department of Industry, Trade and Commerce and Canadian Department of Regional Economic Expansion. 1975. The Canadian potential for industrial particleboard and particleboard products. Vol. I. (Prepared by Columbia Engineering International Ltd., Vancouver).

3. Forest Industries. 1977. Directory of panel plants-USA. Forest Industries 104(3):144.

4. Marcin, Thomas, C. 1977. Outlook for housing by type of unit and region: 1978 to 2020. U.S.D.A. For. Serv. Res. Pap. FPL 304. Forest Prod. Lab., Madison, Wis.

5. National Association of Homebuilders. 1978. Economic news notes. XXIV (1). Washington, D.C. January 24. 4 pp.

6. Statistics Canada. 1978. "Particleboard" Monthly Catalogue No. 36-003. December 1977. 10 pp.

7. Stith, D.J., T.J. Brevik, and L.A. Brooks. 1976. How to figure heat loss and fuel cost. Univ. of Wisconsin--Extension Bull. A1844. Univ. Wis., Madison. November. 11 pp.

8. U.S. Department of Commerce, Bureau of Census. 1978. Housing starts. April 1978. C20-78-4 April. 25 pp. U.S. Dep. Comm., Washington, D.C.
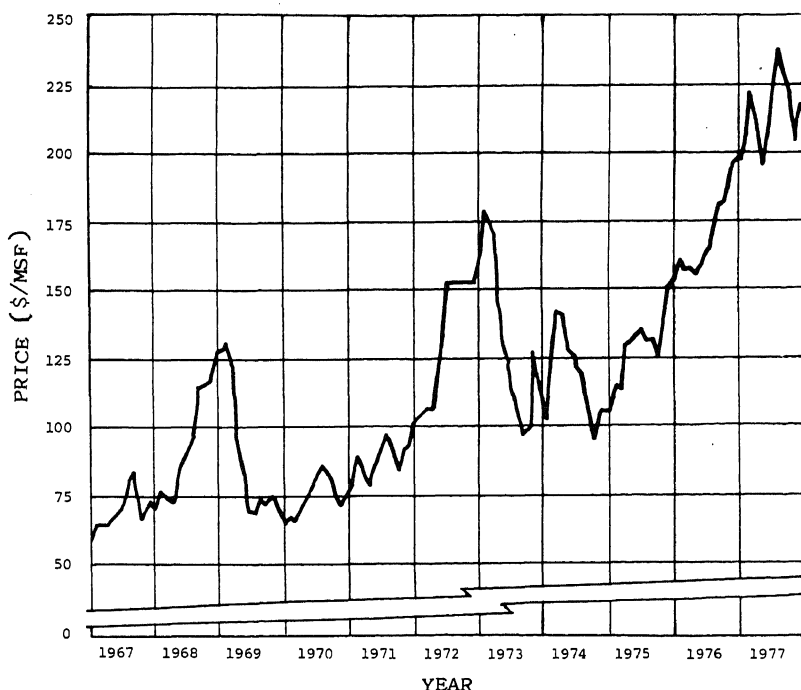
Figure 1.-Average price (f.o.b. mill) of Douglas-fir plywood, 1/2-inch Standard Exterior (3-ply) for 1967-1977.

Table 1. — NEW HOUSING ACTIVITY IN THE UNITED STATES, 1973-77 (8).

| Year | New Public and Privately Owned Housing Starts and Mobile Home Shipments | | | | |
	Total all housing types	Total single and multi-family units	Single-family units	Multi-family units	Mobile home shipments
1973	2,624,400	2,057,500	1,133,200	924,300	566,900
1974	1,681,700	1,352,400	889,100	463,300	329,300
1975	1,384,100	1,171,400	895,500	275,900	212,700
1976	1,793,700	1,547,600	1,166,400	381,200	246,100
1977	2,266,600	1,989,800	1,452,200	537,600	276,800

Table 2.—NUMBER AND PERCENT OF NEW HOUSING UNITS PROJECTED FOR THE UNITED STATES BY CENSUS REGION AND TYPE OF UNIT, 1978-87 (4).

Projected New Housing Demand by Census Region

Year	Grand total all types	Northeast				North Central				South				West			
		Total all types	Single family units	Multi-family units	Mobile homes	Total all types	Single family units	Multi-family units	Mobile homes	Total all types	Single family units	Multi-family units	Mobile homes	Total all types	Single family units	Multi-family units	Mobile homes
						---Thousands of Units---											
1978	2,215	297	149	118	31	463	287	108	68	915	595	172	147	540	320	136	83
1979	2,362	325	161	132	32	495	304	120	71	969	622	191	157	573	335	150	89
1980	2,423	332	164	135	33	504	309	123	73	996	637	198	161	590	343	155	92
1981	2,466	335	167	135	33	508	313	122	73	1,016	655	197	164	606	357	157	93
1982	2,562	348	181	134	32	527	339	116	72	1,056	713	181	161	631	390	149	92
1983	2,611	349	183	134	33	534	345	116	72	1,080	734	182	164	647	402	152	93
1984	2,474	310	162	117	31	493	318	105	70	1,044	713	171	160	627	392	143	91
1985	2,525	312	164	117	31	501	326	105	70	1,069	737	171	161	643	406	145	92
1986	2,537	307	163	113	31	498	328	101	69	1,080	757	163	160	652	419	141	92
1987	2,542	301	161	110	30	493	327	98	68	1,089	771	159	159	658	428	139	92
Total	24,717	3,216	1,655	1,245	317	5,016	3,196	1,114	706	10,314	6,934	1,785	1,594	6,167	3,792	1,467	909
%		13.0	6.7	5.0	1.3	20.3	13.0	4.5	2.8	41.7	28.1	7.2	6.4	25.0	15.3	5.9	3.7

8

Table 3.—AVERAGE ANNUAL PROJECTED FLOOR DECKING, WALL AND ROOF SHEATHING DEMAND IN THE UNITED STATES BY REGION AND HOUSING TYPE FOR THE PERIOD 1978-87.[1]

Region	Housing Type							
	Total all types		Single-family units		Multi-family units		Mobile homes	
	3/8-inch basis	1/2-inch basis	3/8-inch basis	1/2-inch basis	3/8-inch basis	1/2-inch basis	3/8-inch basis	1/2-inch basis
	- - - - - - - - - - - - - - - - - - - MMSF -							
Northeast	1,293	970	976	732	248	185	69	52
North Central	2,089	1,567	1,690	1,268	246	185	153	145
South	3,403	2,552	2,715	2,036	342	257	346	260
West	2,027	1,520	1,542	1,157	288	216	197	148
Total	8,812	6,609	6,923	5,192	1,124	843	765	574

[1]Source: U.S. Forest Service preliminary estimates.

Table 4. — CANADIAN WAFERBOARD PLANT CAPACITY, CORPORATE NAME AND LOCATION OF PLANTS, 1976.

Estimated Plant Capacity	Company Name	Location
MMSF, 1/2-inch basis		
75-83	Alberta Aspen Board, Ltd.	Lesser Slave Lake, Alberta
75-83	Great Lakes Paper Co.	Thunder Bay, Ontario
90-98	MacMillan Bloedel, Ltd.	Hudson Bay, Saskatchawan
75-83	MacMillan Bloedel, Ltd.	Thunder Bay, Ontario
34-38	Waferboard Corp., Ltd.	Timmins, Ontario
75-83	Weldwood of Canada, Ltd.	Longlac, Ontario

REQUIREMENTS, CODES, AND FOREST SERVICE GOALS

Richard N. Jorgensen[1]
National Wood Construction Specialist
Southeastern Area State and Private Forestry
USDA Forest Service
Atlanta, Georgia

Abstract

When the original planning group was established there was only one structural board being produced in the country. Our economists predicted growing and continuing shortages of veneers for structural panels and there were large volumes of forest residues to be used. Performance criteria and goals were established by engineering analysis. Some targets needed more research. Stronger and weaker panels were meeting existing model code and Commercial Standard requirements. New composites were also obtaining code approval. The challenge was to produce from forest residues the best boards possible, designed to meet properties our best engineering judgement deemed would probably and possibly serve structural end uses. We feel the research data you will hear about will provide a basis for producers to manufacture boards from residues to meet model code acceptance standards.

Introduction

To put the research results you will be hearing about later in this symposium into perspective, I must go back to the inauguration of the Task Force and describe its development in relation to my topic. What was the status quo of structural particleboard back in June 1972 when the original Close Timber Utilization Report was approved? It was something like this:

1. There was almost universal code acceptance of phenolic particleboards, some with overlayments, for exterior siding. These were not structural boards but their good record in exposure situations showed a phenolic board would stand up.

2. There was FHA and ICBO acceptance of a planer shaving board made on the west coast. Approval was for thickness equal to plywood only for flooring. The wall and roof sheathing thicknesses required severely limited its use because of the extra weight involved.

3. No other structural boards were being produced in the United States but both waferboard and veneered particleboard were about to appear on the market from domestic factories.

4. Waferboard had been on the market in Canada for over five years and was supplying a surprisingly large percentage

of the sheathing market there after that short time. It was FHA approved for roof and wall sheathing in the same thicknesses as used in Canada.

5. The seventh Particleboard Symposium was about to be held at Washington State University where several engineers would discuss their approaches to basic engineering factors involved in the use of particleboard as a structural material.

Also at that time our economists encouraged the development of structural particleboard and our resource people confirmed a growing and continuing shortage of veneers over the long-time picture, with no slacking of housing and other construction requiring panels. We knew we had much standing and down forest residues and competent scientists to cover all aspects of the development of structural boards from forest residues so the Chief of the Forest Service appointed a planning group in February 1973 and our effort was underway.

The first collaborative work of the group was the development of a Program Evaluation Review Technique chart. A PERT chart is a management technique to control large, complex projects and in our case held dates and responsibilities for each step of the envisioned five year plan. The schedule was adhered to and this seminar is being held only two months after the PERT chart calls for the technology transfer. Although modified somewhat over the years it was an excellent control tool.

Two critical paths were involved; the development of panels, and a residue resource review and recovery strategy. Along the panel development control path the first item allowed two months for the formulation of performance goals. Without a dated literature review, what were some of the general aspects to consider in this formulation? We could see that:

1. One material, plywood, was already serving in the capacity visualized for structural particleboard and its physical and mechanical properties provided an indication of the type of material which could do the job involved. However, it was realized there were certain limitations on the production of boards from residues and it would probably be impossible to duplicate completely the properties of plywood.

2. Waferboard, less stiff and less strong than plywood, was performing

---

[1]Stationed at Alexandria, La.

satisfactorily in Canada and was FHA approved.

3. A Commercial Standard was, and still is, in existence describing a phenolic board which could be used for structural pruposes but no code body had approved such a board in equivalent thicknesses to plywood.

4. The major model codes all had floor, wall and roof strength and stiffness requirements which would have to be met by a marketable product. This was a doubly restrictive condition in that it affected both the physical and the mechanical properties and held a still unanswered question as to what the building industry would accept in a panel product. It was also probably the most important consideration since we knew that without code approvals the product would never be able to be widely used.

We viewed the challenge as one that required we produce the best boards possible, not necessarily equal in all properties to plywood, but sufficiently designed to meet properties the best engineering judgement of the day could give us about a product that possibly and probably could and would serve the same end uses.

So a group of our engineers developed performance criteria for six major properties. Each area included state-of-the-art proposals based on past research results, recommended design and analysis methods and recommendations for future research where deemed necessary. Items such as safety factors as an engineering judgement and load duration factors which would be determined by future research were necessarily part of these calculations. The performance goals set up for the Task Force as a result of these studies were as follows:

Modulus of elasticity	800,000 psi
Near minimum modulus of rupture (5% exclusion level)	4,500 psi
Internal bond	Dry; 70 psi After D 1037 (1): 30 psi
Linear expansion 30-90% RH	4' x 8', 4' x 9': 0.25% Over 9': 0.20%
Thickness swell 30-90% RH	8.0%
Lateral racking	FHA Tech. Circular No. 12 (4)
Time-dependent deflection	Research needed
Direct nail withdrawal (all nails driven dry)	Dry: 40 lb 24-hour soak: 25 lb After D 1037: 20 lb
Density	37 to 43 pcf
Impact	National Housing Agency Performance Standards until further research done.
Fire and Smoke	NFPA Life Safety Code (2)

These are the targets we have been aiming at. How close we have come will be reported in detail as the seminar continues.

Meanwhile, the plywood shortage occurring in late 1972 and early 1973, at the time these goals were being developed, led to an increased market for waferboard on the east coast and particularly in the state of New Jersey. In late 1972 the New Jersey State Building Code approved the use of Canadian waferboard for sheathing in thickness dimensions equivalent to those in use in Canada and equivalent to the FHA approval memorandum. Many carloads of the material were brought into the state and were widely used by both large and small builders. As plywood production began to catch up with the shortage, the supply and the price differentials between the two disappeared and some builders went back to plywood while others continued to use the waferboard. Waferboard continued to be used under the FHA Memorandum Approval until 1975 when a formal Materials Release was issued.

Also during this five year period west coast model code approval was obtained for both oriented particleboard and veneer-faced oriented particle coreboard. The properties of both these boards are considerably higher than possible with a standard random particleboard and close to those of plywood. The veneer faced board has since then been approved by other model code bodies.

Encouraged by the East Coast acceptance of waferboard, the Canadian producers applied for approval to the Building Officials and Code Administrators International, the Southern Building Code Congress, and to the International Conference of Building Officials and as of this date have received appropriate approval from each of these model codes. A U.S.-produced waferboard is also approved by BOCA. These boards are approved for roof sheathing at 3/8 inch on 16-inch o.c. rafters and 7/16 inch on 24-inch o.c. rafters and as wall sheathing 5/16 inch on 16-inch o.c. studs and 3/8 inch or 7/16 inch on 24-inch o.c. studs without corner bracing. These boards conform to type and grade 2B2 of CS 236-66 (3) which calls for minimum averages for modulus of rupture of 2,500 psi and modulus of elasticity (MOE) of 450,000 psi. Actual production boards usually

psi. Actual production boards usually run about MOE = 600,000 psi. A satisfactory service record of the waferboard in Canada and in the United States has helped gain approval of this board.

The regulatory community and a growing segment of the market place have then, five years after the Task Force establishment, accepted boards with properties exceeding the original goals of the Force and boards considerably lower than those goals. With 100 percent accurate hindsight it appears now, five years later, that the Task Force got off to a good start in its direction. The scientists will explain in detail how their results have satisfied the goals set for them and the new developments which were indirect ramifications of attempts to meet those goals.

Since we now have nationwide model code acceptance and widespread local code acceptance of boards for roof and wall sheathing which are considerably less stiff and less strong than those developed by this Task Force, we are confident that research data that you will hear about at this seminar will provide a basis for producers to manufacture boards from residues to meet model code acceptance standards. The engineering data used in formulation of the goals included use as floor panels. When you hear the accomplishments of our scientists you can form your own opinions on floor panel applications. At this time we are doing and supporting further work on other uses for the types of boards made from residues. Some of their characteristics certainly make it seem possible that there will be expanded uses in the future for these types of engineered panels.

References

1. American Society for Testing and Materials. 1977. Standard methods of evaluating the properties of wood-base fiber and particle panel materials. ASTM Desig. D 1037. ASTM, Philadelphia, Pa.

2. National Fire Protection Association. 1976. Code for safety to life from fire in buildings and structures. NFPA 101-1976. N.F.P.A., Boston, Mass.

3. U.S. Department of Commerce, National Bureau of Standards. 1966. Mat-formed wood particleboard. Commercial Standard CS 236-66. U.S. Dep. Comm., NBS, Washington, D.C.

4. U.S. Department of Housing and Urban Development, Federal Housing Authority. 1969. A standard for testing sheathing materials for resistance to racking. FHA Tech. Circular 12, U.S. Dep. HUD, FHA, Washington, D.C.

FIBER FOR STRUCTURAL FLAKEBOARD--MECHANIZED THINNING AND TOPWOOD RECOVERY

R.A. Arola[1]
Project Leader
North Central Forest Experiment Station
USDA Forest Service
St. Paul, Minnesota

Abstract

Case studies in mechanized thinning of pole-sized hardwoods by the Forest Service's engineering research project at Houghton, Michigan, have demonstrated that significant amounts of thinnings can be recovered economically by a completely mechanized system and still improve the residual stand quality and growth. Additionally, an experimental topwood processor has shown considerable promise in recovering massive hardwood tops and limbs. A new chipping machine was developed that turns residue into particles suitable for subsequent ring flaking and use as structural flakeboard furnish.

Introduction

In 1973 the Forest Service organized the Close Timber Utilization (CTU) program to improve forest utilization and reverse the present practice of ignoring those forest residues which are normally left in the woods to rot. Included are the unsightly logging residues, slash, and standing dead and dying trees. Part of the reason for leaving these residues behind was the questionable economics of recovery and lack of viable markets.

An integral part of the CTU program was a service-wide, multidisciplinary research program to develop the technology to make the use of forest residues for structural flakeboard economical. The implications of such a revolutionary development are exciting since exterior grade structural plywood, which normally requires straight, high quality, peeler bolts, could be replaced by an engineered flakeboard made from logging waste, small diameter or crooked materials. Additionally, the benefits derived from extending quality timber supplies are equally exciting. Three broad problems need solutions: 1) the development of flakeboard performance requirements; 2) development of methods for harvesting, processing, and transporting forest residues; and 3) development and evaluation of structural board from residue-derived flakes.

The Forest Engineering Laboratory, located in Houghton, Michigan, which conducts research to promote more efficient mechanization of forestry operations in the North Central States, was charged with two principal tasks in this forest residues to flakeboard program. The first was to identify and assess those wasted

residues which could furnish significant fiber for structural flakeboard and to conduct research on new systems and equipment concepts to permit economical recovery of these residues. The second mission was to develop a machine capable of field chipping typical residues and small diameter trees for transport to a mill and conversion into flakes for flakeboard.

Two high-volume residues were chosen: 1) thinnings from pole-sized northern hardwood stands, and 2) tops and limbs from conventional hardwood sawlog operations. The foresection of this paper presents the results of research to recover these two problem forest residues. The second section discusses the development of an experimental spiral-head chipper to render these forest residues into particles suitable for ring flaking.

Mechanized Thinning of Pole-Size Northern Hardwoods

The Forest Service's "Outlook for Timber" report (14) details the supply/demand forecasts for hardwoods as well as the general condition and quality of our hardwood forests. The projected demand for hardwood to year 2000 is expected to increase more than two-fold, to reach 7 billion cubic feet. Of this, 19 billion board feet is the expected demand for hardwood sawtimber. A direct comparison of supply/demand statistics could yield misleading conclusions. The fact is, although we are currently growing more hardwood volume than is being harvested, there is a definite decline in the quality of hardwoods. Much of the hardwood growth and available supply is in small trees or species with limited markets; large trees of preferred species are in short supply in most hardwood areas. Problems of supply are compounded by a declining land base caused by increasing public pressures for agriculture, recreation, wilderness, and wildlife.

In the Northeastern United States there are approximately 32 million acres of the maple-beech-birch forest type, approximately 9 percent of the eastern forest land area (10). In the Lake States area of Michigan, Wisconsin, and Minnesota, approximately 23 million acres out of about 50 million acres of commercial timberland are classified as pole-timber (Table 1). Much of this pole-timber currently needs thinning. Additionally, over 14 million acres of

Table 1.--LAKE STATES COMMERCIAL TIMBERLAND

State	All Classes	Poletimber	Seedlings and Saplings
	----------Million acres-------------		
Michigan	18.8	8.1	5.5
Wisconsin	14.5	6.6	4.5
Minnesota	16.9	8.4	4.2
Total	50.2	23.1	14.2
%	100	46	28

Table 2. — STOCK AND STAND TABLE (PER ACRE) FOR ENTIRE
50 ACRES BEFORE THINNING (2)

D.b.h.	Sugar Maple			Red Maple		
	Trees	Volume	Volume (25% of trees)	Trees	Volume	Volume (55% of trees)
In.	No	Cords	Bd. ft	No	Cords	Bd. ft
5- 9	35.32	1.65	--	83.72	4.08	--
10-14	13.17	1.07	295	34.54	3.42	384
15-19	4.46	0.06	707	1.62	0.08	204
20+	0.55	--	125	0.10	--	23
Total	53.50	2.78	1,127	119.98	7.58	611

D.b.h.	Other Species[1]			Total			
	Trees	Volume	Volume (20% of trees)	Trees	Basal area	Volume	Volume
In.	No	Cords	Bd. ft	No	Ft^2	Cords	Bd. ft
5- 9	17.55	1.16	--	136.59	37.49	6.89	--
10-14	21.38	1.68	485	69.09	45.55	6.17	1,164
15-19	3.42	0.29	383	9.50	14.63	0.43	1,294
20+	0.32	--	66	0.97	2.29	--	214
Total	42.67	3.13	934	216.15	99.96	13.49	2,672

[1]In the western Upper Peninsula of Michigan these second growth hardwood stands
are primarily composed of sugar maple (Acer saccharum), red maple (Acer rubrum)
and yellow birch (Betula alleghaniensis). There are lesser amounts of black
ash (Fraximus nigra), American elm (Ulmus americana), black cherry (Prunus
serotina), hemlock (Tsuga canadensis), balsam fir (Abies balsamea), and red oak
(Quercus rubra). The maple, oak, birch, and cherry are valuable commercial
species commanding a high price when saw log size.

seedlings and saplings will need future thinning. Crowding becomes serious, long rotations are frequently required to produce merchantable timber, and stagnation may occur on poor sites resulting in a deficient, unmerchantable stand. Further, many trees are sprouts and are of poor form, forked, short, and generally worthless as sawtimber if left to mature. Limited acreages of these stands are actually thinned each year to promote quality growth. Trees felled in thinning are traditionally left in the forest to decay. This thinning practice, although it ultimately improves the stand, yields no immediate net return to the landowner. It is but a direct outlay of capital.

A concerted effort is needed to improve the quality and quantity of hardwood stands--a dedicated program of thinning of pole-size hardwoods for timber stand improvement (TSI). However, the major hurdles to dedicated TSI are economics and markets.

Selective chain saw thinning, besides being wasteful, is very labor intensive and costly. Typical costs for chain saw thinning in Michigan range from $25 to $35 per acre. The practice of TSI in northern hardwoods must be transformed from a labor intensive, costly, and wasteful practice into a completely mechanized system geared to profitable recovery of thinnings.

Mechanized Thinning Case Study

The North Central Forest Experiment Station's Forest Engineering Laboratory, in cooperation with the Michigan Department of Natural Resources, investigated the productivity and economics of mechanically thinning northern hardwoods. A poletimber stand in Ontonagon County, Michigan, was thinned during the fall of 1974 (2). The study objective was to demonstrate the commercial viability of mechanized TSI whereby the thinned products from second-growth, northern hardwood pole stands are recovered at a profit. Although the recovered thinnings from the case study were converted to pulp chips because a market existed, such thinnings could as well be converted to a product form more suitable as furnish for structural flakeboard. Conventional pulp chips are not suitable for flaking. Production of a "fingerling" particle which can be ring flaked will be discussed later.

Stand Description and Thinning Treatment

A 50-acre stand of mixed species, predominantly pole size, on essentially level terrain with well drained, sandy loam was selected in the Mishwabic State Forest in Michigan's Upper Peninsula (Fig. 1A). A preliminary survey indicated 13 cords of hardwood pulpwood and

2,700 board feet of small sawlogs per acre (Table 2). Initial basal area was about 100 square feet per acre in trees 6 inches d.b.h. or larger. Although tree diameters ranged from less than 2 inches d.b.h. to 28 inches, average tree diameter was slightly less than 6 inches. The stand, which was equally bisected by an existing woods road requiring improvement, was further divided into ten 5-acre plots measuring 330 feet wide by 660 feet deep. Landings were located at each end of the woods haul road bisecting the stand.

Five thinning treatments, four fully mechanized, were tried with two replications per treatment. The mechanized treatments were: 1) strip thin only; 2) strip thin with selection thin between strips; 3) selection thin only; and 4) a shelterwood cut. The base treatment was a conventional chain saw TSI cut where the felled trees were left on the forest floor (Fig. 1B).

The stand was thinned to a residual target basal area of 65 square feet with the exception of the shelterwood cut which was cut to a 70 percent crown cover. In shelterwood cutting the purpose of the first thinning cut is to remove a certain portion of the overstory to open up the stand but still leave a residual overstory to provide seed and shelter for establishment of new growth.

Equipment

Conventional equipment was used to thin the test tract. The three major pieces of harvest equipment used were: 1) a John Deere 544 feller buncher with a Rome accumulator shear (Fig. 1C); 2) a Clark Ranger 667 grapple skidder; and 3) a Trelan D-60 whole-tree chipper.

Productivity

Of the test treatments, strip thinning with selective thinning in the leave strip (Fig.2) proved most promising because it produced the most chippable wood, was the easiest to do in terms of men and machines, caused the least damage to the residual stand, and left the residual stand esthetically pleasing. The second favored study treatment was the sheltered cut (Fig. 1D). The total yield of chips and sawlogs on the nominal 40 acres mechanically thinned was 1829 green tons (Table 3). The majority was in material converted to chips. Approximately 3 percent of the total recovered tonnage was sorted out at the woods landing as saw-

Table 3. -- MATERIAL RECOVERED FROM MECHANIZED HARDWOOD THINNING (2)[1]

Treatment and Size (Acres)	Chips Removed Tons	Saw logs Removed Bd. Ft.	Total Removed Tons	Total Removed Per acre Tons	Total Removed Per acre Stems
Strip (10.5)	342	2,760	359	34.2	186.2
Shelterwood (9.6)	470	2,670	486	50.6	255.0
Selective (9.5)	444	1,380	453	47.7	219.2
Strip with selective (9.5)	513	2,830	531	55.9	263.9
Total	1,769	9,640	1,829		
Average				46.8	230.0

1 All tonnages are green weight.

Table 4. -- BREAKDOWN OF 1974 MECHANIZED THINNING COSTS (3)[1]

Item	Equipment	Labor	Total	Percent of Total
	------- $/Green ton ----------------			
Feller-buncher	1.13	.68	1.81	21
Skidder	.94	.68	1.62	19
Chipper	1.29	.68	1.97	22
Chain saw	.03	.27	.30	3
Maintenance and fuel truck	.06	.41	.47	5
Chip van	.48	.31	.79	9
Highway truck	1.40	.31	1.71	20
Landing truck	.04	.07	.11	1
Total	5.37	3.41	8.78	100

1 Average of all thinning treatments on 40 acres.

Table 5.--TWO-YEAR DIAMETER GROWTH FOLLOWING MECHANIZED THINNING [1]

Species	Strip Only	Strip W/Select.	Select. Only	Shelterwood
	--------------------- In-------------------			
Sugar Maple	0.150	0.062	0.100	0.220
Red Maple	.164	.200	.178	.244
Black Cherry	-	.267	.400	.200
Red Oak	.200	-	1.100	.600
Hemlock	.100	-	-	.100

1 First retally of 4 selected compartments.

logs. The average yield per acre was 46.8 green tons from 230 stems. The strip with selective thinning between strips averaged 55.9 tons per acre from 264 stems. Hourly productivity ranged between 13 to 26 green tons per hour and averaged 17 tons per hour.

For the various thinning treatments under which the feller buncher with accumulating shearhead operated, the stem productivity ranged between 2.7 to 2.9 stems per cycle which did not make up a skidder load. The stems per skidder load generally ranged between 9 to 11 trees which in turn ranged in weight between 1.7 to 2.6 green tons. Total skid time varied between 6 to 11 minutes including delays. The average number of stems per vanload was 116 stems which took 84 minutes to chip conventionally and fill a 20-ton van.

The schematic of Figure 2A shows why the strip with selection system was preferred. Initially the feller buncher starts cutting a 10-foot wide strip laying all shear accumulator bunches to the right. At the end of each strip (10 chains in this case) the operator begins to work the unthinned leave strip to his left and selectively thins up to where the next strip will begin (70 feet in this study). The trees removed from the selectively thinned area are bunched in the previously cut strip. This procedure minimizes damage to the residual stand and also concentrates all of the cut material either in the cut strip or adjacent to it. After finishing the selective thinning in the leave strip, the feller buncher operator repeats the process by moving the leave strip distance to the left and begins a new strip, again laying bunches to the right and into the thinned area he just finished cutting. Progressing in this manner, interference between the felling and bunching and the skidding operation is avoided. Since all material is concentrated in or adjacent to a strip, the skidder operator can easily follow the cutting pattern without making skid route decisions.

Production Costs

The total 1974 purchase price of the equipment was about $219,000. Hourly operating cost, including depreciation, interest, taxes, licenses, oil, gas, and other miscellaneous costs was $92.61. Wages and overhead for the 5-man crew was an additional $35.25 per hour, making a total hourly operating cost of $127.86 for labor and equipment if all the equipment was operating at the same time. This was never the case because equipment such as spare vans and yard tractor only operated part of the day. An analysis of labor and equipment costs in dollars per ton, excluding stumpage, marking, and

site preparation costs, yielded a total production cost of $8.78 per ton of green chips (Table 4). Sixty-two percent of the cost was attributed to the felling, skidding, and chipping, while 30 percent was associated with trucking.

A break-even analysis was made for the entire operation (Fig. 3). The fixed thinning cost was $593 per day to cover labor, depreciation, interest, insurance, taxes, licenses, plus other miscellaneous fixed costs. The hourly equipment operating cost was $36.77. Using the average productivity of 17 tons per hour and an actual revenue at the time of the study of $11.85 per green ton of chips delivered to the mill, break-even was reached after approximately 3-1/2 hours of operation. The break-even chart clearly justifies working a full 8-hour day to maximize profits.

The following tabulation reflects total stump-to-mill jobber costs which include both nonproduction and production costs. These costs, which do not include a margin for profit, represent 1974 study costs plus estimated 1977 costs.

In 1974 dollars with a jobber cost of $9.60 per delivered green ton and an actual revenue of $11.85 per green ton, the profit margin was $2.25 per green ton. The per acre profit using the average yield of 44.9 green tons per acre for strip with selective thinning was $125.78. Compare this to the direct cost of selective chain saw thinning on the control plot of $33.52 per acre with no product recovery.

Damage

Since northern hardwoods are very susceptible to decay, it is essential that the residual trees are not so severely injured that they will become worthless. Therefore, apparent stand damage was recorded (2).

Mechanized thinning injuries occurred more frequently than in previously reported chain saw thinning studies. However, it is expected that most injuries are relatively minor. Many of the damaged trees can be removed at the time of thinning or in future thinnings and according to previous studies, before significant volume or value losses occur in these young, vigorous stands (8). Many of the damaged trees occurred adjacent to the strips and on the pivot trees where the strip meets the woods haul road. Conceivably, high residual stumps could be left as bumpers for future thinnings. As operators become more proficient at mechanized thinning and as systems improve, tree injuries will lessen.

Two full growing seasons after harvesting, the site was re-examined for

| | Thinning costs | |
	1974 case study	1977 estimated
	$/Green ton	
Production		
Harvest	6.18	7.42
Transport	2.60	3.12
Nonproduction		
Stumpage	.50	.60
Marking	.10	.12
Roads and landings	.22	.26
Total	9.60	11.52

early effects of logging damage on regeneration and individual tree growth. Although the area had been extremely dry both growing seasons, which likely had some adverse effect on regeneration and establishment of seedlings, sprout growth was unaffected. Seedlings of all species were not as abundant as expected but seed production was felt sufficient to regenerate desirable tree species. The presence of stump sprouts may present future problems.

Trunks of trees that had suffered bark wounds showed callous growth developing. Many showed vertical spread from the initial wound under the bark and deeper wood discoloration than expected. However, it appears too early to conclusively evaluate wound severity.

Growth

Individual tree growth after two years was checked (Table 5). Overall, northern red oak grew best (one tree grew 1.1 inches), followed by black cherry, red maple, sugar maple, yellow birch, and hemlock. Although not conclusive because of small sample size and observations from only two growing seasons, shelterwood appeared to have the most overall diameter growth, followed by strip with selection, selection only, and strip only. Despite the unusually dry conditions for two seasons, the stand appears healthy and responding to thinning. The shelterwood site as it existed in August 1977, three growing seasons after harvesting, looks pleasing (Fig. 1D). Fertilization of thinned stands during or after mechanical thinning may increase growth (13).

Topwood Recovery

Hardwood Residues Case Study

To establish the potential for recovery of tops and limbs, an assessment of these residues was made following commercial improvement cuts on a northern timber sale (9). Measurements on 1-acre circular plots revealed that close to half of the above-ground portion of the hardwood trees was left in the woods following logging--tops and limbs amounted to 41 percent for sawtimber trees and 49 percent for poletimber trees.

Other residues, such as cull sections, unmerchantable trees felled for stand improvement but left behind in their entirety, and trees knocked over or broken during logging, were also categorized by size and weight. Approximately 85 percent of the total residues found were attributed to sawtimber and poletimber; the remainder was in knocked-over or no-product trees (Fig. 4A). Considering material only 3 inches in diameter and larger, the combined sawtimber and poletimber categories accounted for 80 percent of the plot residues (Fig. 4B). Approximately 55 percent of the top and limb residue in both sawtimber and poletimber trees was greater than 3 inches in diameter (Fig. 4C, 4D). The total of all residue classes was close to 18 green tons per acre. About 10 green tons per acre of material was greater than 3 inches in diameter.

Top and limb residue in sawtimber trees amounted to almost 47 green pounds for every cubic foot of product removed and close to 65 pounds of residue per cubic foot of product removed in poletimber. The average green weight per tree in tops and limbs was about 1500 pounds in sawtimber and 480 pounds in poletimber. A separate study related the residue weight for sugar maple sawtimber trees over a range of tree diameters (Fig. 5) (12).

It appears too costly to post-log to recover only the straight shortwood sections by cutting and gathering at the stump and then forwarding. Recovery of entire tops with limbs intact is a possible approach but may likely be unacceptable because of root and bole damage to the residual stand (3,11). This damage may be especially severe if recovery is during the summer months when bark is loose. Damage may be significantly less if recovery of entire tops is during the dormant months when bark is tight.

Testing of a Prototype Topwood Harvester

Forest engineering research in the North Central States has developed a unique concept to recover tops and limbs from hardwood sawlog operations. The concept developed is to render large hardwood tops (Fig. 6A) into a compacted form more suitable for grapple skidding (Fig. 6B). To prepare tops in this fashion, an experimental topwood harvester employing a small, highly maneuverable, hydraulically actuated shear was designed

18

and specially mounted on a knuckle boom of a carrier vehicle. The specially designed mounting device is a principal feature because the shear assembly can be rotated to practically any orientation. This maneuverability makes it possible to sever the large protruding limbs and align them with the butt of the main stem of the top. Once all large limbs are severed and aligned, the compacted top is ready for forwarding to a woods landing.

The study[2] objectives were to: 1) evaluate a completely mechanized system for recovering hardwood tops and limbs (Fig. 7); 2) test the capabilities of the prototype topwood harvester; 3) evaluate residual stand damage; and 4) determine production volumes and costs associated with topwood harvesting in a selectively logged northern hardwood forest.

At the time of this writing, the topwood harvesting study is in the final stages of completion. Therefore, all data and results presented are preliminary. Future publications will report the final study results and data in detail.

The study area contained 21 acres and is located at Michigan Technological University's Ford Forestry Center about 10 miles south of L'Anse, Michigan. A pre-harvest inventory indicated a volume of 7 thousand board feet (Net Scribner) and 6 cords of hardwood per acre. The soil is a well drained, coarse, gravelly loam. The tract is on level terrain traversed by an all weather road. Previous selective logging was conducted in 1938 and 1967. The 1977 estimated harvest is 1800 board feet and 5 tons of hardwood pulpwood per acre. Although very little topwood volume was utilized during the conventional sawlog harvest, 107 tons of hardwood pulpwood was later removed from the residual tops before recovery of tops. Had that portion been left with the original tops, an additional 5.1 tons per acre would have been recovered during topwood removal, thus making the economics of topwood recovery more attractive. This especially applies to the well managed test stand-- sawlog volumes were high and topwood volumes low (Table 6).

The prototype shear assembly was capable of severing and bunching hardwood limbs up to 12 inches in diameter. The carrier vehicle, a Gafner 4000 series mini-skidder, had a rear-mounted boom to which the shear was attached by a highly flexible coupling mechanism (Fig. 8). The skidder was specially outfitted with a sophisticated remote control hydraulic system which incorporated all operational functions into two "joystick" control devices plus one foot pedal. With operator experience, this control system should allow fast and efficient operation. The prime mover was not selected on the

basis that it was an ideal machine, but because of its availability.[3] This experimental harvester was used to cut and bunch only large tops. The operator skipped small tops not having large protruding limbs. It was felt the small tops would not create objectionable residual stand damage during forwarding.

Following cutting and bunching, the tops were skidded by a Clark Ranger 667GS grapple skidder to a Morbark Model 22 Whole Tree Chipper (Fig. 7). All recovered tops were chipped and blown into two large piles, one of which had estimated cubic foot top volumes for all chipped tops in that pile. It was this pile that was weighted. A chain saw operator was located at the landing to sever any remaining large limbs which still hindered the chipping operation. The number of chain saw cuts were recorded. A detailed time study was conducted on topwood processing, skidding and chipping operations to establish performance and operating costs.

Results of Topwood Harvesting

The prototype topwood harvester was used to cut and bunch 115 tops (Table 7, Fig 9). Additionally, 40 tops were passed over by the operator because it was felt they were too small to require processing. Of the 115 processed tops, the extent of processing ranged from bunching only (no cuts) to a maximum of 7 cuts per top with a mean of 2.3 cuts per top. If all 155 tops were considered as processed, the average cuts per top are reduced to 1.7. Diameters of cut limbs ranged from 2 to 11 inches with an average of 6.3 inches (Fig. 10). The average time to process the tops was about 4 minutes without delay and slightly under 6 minutes per top with delays (Table 8).

The topwood harvester delays include: 1) unavoidable delays, such as operator decision-making prior to processing, cutting saplings which impeded topwood processing, and repositioning of moving limbs to improve accessibility to complete a top; 2) mechanical delays although normally included in the production figures as unavoidable, were listed separately because "prototype debugging" delays would normally be eliminated in a production machine--these delays typically

[2]A cooperative study between the USDA Forest Service and Michigan Technological University entitled "Field Evaluation of Topwood Recovery System From Hardwood Saw Log Tops."

[3]Memorandum of understanding between Gafner Machine, Inc., and North Central Forest Experiment Station, USDA, April 30, 1976.

Table 6. -- TOPWOOD HARVESTING PRODUCT INFORMATION

	Study Plot Averages	Per Acre
Number of sawlogs removed	--	20.6
Gross board feet removed (Scribner)	--	2,087
Net board feet removed (Scribner)	--	1,924
D.b.h. of trees (in)	17.7	--
Height of trees (ft)	76	--
Crown width (ft)	23	--
Crown length (ft)	37	--
Diameter of butt end of residual top (in)	12.1	--
Top weight (tons)	.7	7.33
Hardwood pulpwood removed[1] (tons)	--	5.1
Total tops[2]	--	14.5

[1] Pulpwood was removed prior to topwood recovery.
[2] Includes processed, unprocessed and tops not recovered (lost in deep snow).

Table 7. -- SUMMARY OF TOPWOOD HARVESTER DATA

	Processed	Skipped
Total tops	115	40
D.b.h. of trees (in)	18.7	13.2
Height of trees (ft)	79	68
Top width (ft)	27	17
Top length (ft)	37	37
D.o.b. of butt end (in)	13.4	9.1
Relative volume[1]	3	1

[1] Relative volume of processed was approximately three times greater than the unprocessed tops.

Table 8.--BREAKDOWN OF AVERAGE PROCESSING
TIME PER TOP

	Time Min.
Time per top (without delay--100% utilization)	4.1
Unavoidable delay	.2
Mechanical problems	.8
Avoidable delay	.6
Total time per top	5.7

included problems with the controls, shear blades, and oil leaks from loose or poorly protected fittings; and 3) avoidable delays related to the prime mover, such as lifting and lowering stabilizer pads and climbing in and out of the two seats which was required for operation of this particular machine. A more desirable machine would eliminate these delays. Lunch and breaks are not included in the reported delays.

Since all of the chips have not been hauled and weighed at the time of this writing, the data reported are based on a preliminary study estimate of 0.7 green tons per top. These data may require future moderate adjustments after all recovered chips are weighed and correlated to number of tops.

Topwood harvester productivity was only 10.2 tons per hour (without delays), whereas the number of tops processed to produce this amount was quite high at 14.6 (Table 9). Previous studies (9) have shown that in similar stands where prior product utilization was not so high, nearly half of the weight of harvested trees was left in the woods. If the 107 tons of pulpwood were not removed prior to topwood recovery, the topwood harvester would have processed about 15.3 tons per hour.

Excluding all delays, the topwood processing cost was $2.25 per green ton ($1.58 per top) (Table 9). Had the average 5.1 tons of previously recovered pulpwood been left with the original tops, the estimated costs associated with cutting and bunching would decrease from $2.25 to $1.51 per green ton.

The above figures include no delays. A 20 percent decrease in productivity resulted when including only the unavoidable delays defined earlier. Also, productivity is expected to increase as the operator develops more skill and confidence in processing tops in this manner and becomes more familiar with the "joystick" control system. A general observation was that the operator should process the tops much more aggressively, and mentally plan his processing approach before proceeding. In this study the operator lost time due to "wrong" decisions in cutting and positioning of limbs.

Skidding costs were higher than anticipated (Table 9). Based on a 1700-feet round trip skid distance and average payload of 0.84 tons per grapple load the cost of skidding was $4.38 per green ton (without delays). (Compare this average skid load to the thinning study previously described where 9 to 11 pole-sized whole trees made up a skidder load and ranged in weight from 1.7 to 2.6 green tons.) As suggested earlier, had the sections previously removed as pulpwood

been left with the original tops, the estimated skidding costs were calculated to decrease to $2.92 per green ton. Skidding and chipping was done in mid-winter under severe conditions. Many tops were nearly completely covered by deep snow and the skidder had difficulty maintaining traction. Some tops were frozen to the ground and needed to be broken free. It is believed that an increase in productivity of at least 10 to 20 percent could have been realized had better conditions existed.

Chipper utilization was very low because only one skidder was used. Actual chipping productivity was less than 5 tons per hour (includes all delays) (Table 9). At 100 percent utilization, the chipper productivity was 17.5 green tons per hour which yielded a cost of $2.57 per green ton. The productivity and cost data of Table 9 clearly show the need to keep the chipper supplied with material.

There was still a need to sever some limbs or stubs which would not feed into the chipper. Of the 220 tops chipped, 160 of them required at least one chain saw cut. Many of the tops which had been pre-cut by the topwood harvester had short stubs protruding which restricted proper feeding and had to be removed. This function was not time consuming but necessary--the chain saw cost was $.18 per ton. An improved topwood processor design may permit removal of limbs closer to the main stem and eliminate the short stubs. The weakest link in the operation was skidding. The chipper averaged one ton of material in 3.4 minutes compared to skidding the same ton in 8.1 minutes (Table 10).

In comparing cost, the topwood harvester was the least expensive, processing at the 100 percent utilization rate of $2.25 per ton. Total harvesting, excluding trucking, amounted to $9.38 per green ton (Table 9). This cost is estimated at $6.32 per green ton had the pulpwood been left with the tops as previously suggested.

Following the conventional selective sawlog harvest a post-logging damage assessment was made on several 1/5-acre circular inventory plots. All felling and skidding damage associated with the original selective logging was identified and marked. Following topwood harvesting all new damage was also recorded. At this time, the assessment of damage to the residual stand has not been completed but will be reported on in the final publication describing this research. However, a brief inspection of the residual stand shows relatively minor damage. This was perhaps one benefit of the deep snow which acted as a cushion. Also a benefit was the season of the year; in winter the

bark is tight.

Topwood Recovery Observation and Recommendations

Critical evaluation of this one-of-a-kind study permitted identification of various problems that could be eliminated by better planning of future systems to increase system efficiency.

Most sawtimber operations leave behind large tops from which no pulpwood sticks have been removed. This seems desirable because the main stem of the top can be more easily fed into the chipper throat. This reduces the processing time per top, even though more tonnage is chipped. The feed rolls have difficulty engaging a branch top that has no main stem.

Even though processed tops were more compact, they were still difficult to skid. For the particular skidder used, in some instances it was much easier to skid uncut tops than cut tops because some pieces had a tendency to slip out of the grapple when the load shifted. A skidder with a constant pressure grapple may lessen this problem. A grapple skidder with a cable system for tightening the grapple load seems a better choice. Future studies might compare choker skidding with grapple skidding including the combination of grapple with internal cable.

When skidding small tops (such as those in this study which averaged about 0.7 tons per top) two small skidders with a payload capacity of about 1 ton may be a better choice (skidding with a single skidder limits productivity).

For this study, a chainsaw operator was stationed at the chipper at all times to make any necessary cuts on the tops so they could be chipped. Since this operator was utilized only 12.5 percent of the time, it might have been just as effective to have the chipper operator do his own chainsaw work. Or, another approach is to replace the conventional chipper grapple with the type of grapple design which incorporates a hydraulically actuated chainsaw built within the grapple and controlled by the chipper operator.

The chipper used in the study had a grapple with large teeth welded to its outer edges. This enabled the operator to place the closed grapple within limb junctures, and upon opening, the grapple would split the two limbs. This innovative grapple modification functioned very well for this purpose.

With time study data obtained from this study, plus use of an existing topwood harvesting computer simulation model, various alternatives will be tried on the computer, including more realistic skid distances.

Development of a Spiral-head Chipper

The "Fingerling" Concept

An early concept developed at the Forest Products Laboratory, Madison, Wisconsin, formed the basic guidelines of what intermediate product form forest residues should be reduced to (6,7). This idealized concept was to produce particles of elongated dimensions in the fiber direction--approximately 2-1/2 to 3-inches long with a nominal cross-section of 1-inch by 1-inch. These idealized particles, termed "fingerling" would then be ring flaked to a thickness of approximately 0.015 to 0.02 inch. These long, thin flakes were believed to be ideal for producing either an aligned or randomly oriented flakeboard. The flake aligned boards would have superior strength properties in the direction of alignment. The aligned flakeboards would then be alternately layered, as veneer sheets are in plywood, to produce an engineered flakeboard having desired strength properties and characteristics.

The task assigned to the Forest Engineering Laboratory in Houghton, Michigan, was to develop a concept for a woods-portable machine which would render small-sized forest residues into "fingerling" particles (Fig. 11). In-woods fingerling production was deemed essential because of the high cost and problems associated with handling and transporting small diameter and crooked residue materials. The more homogeneous fingerlings are much easier to handle and transport in bulk.

The failure of conventional chipper to produce particles having the desired fingerling geometry make them unsuitable. Also, a review of current wood cutting mechanisms did not reveal how the idealized fingerling particles could be produced. It was therefore apparent that a completely new chipping concept was needed. The resultant mechanism was a very novel spiral screw-type cutterhead mounted on a rotary shaft. A simple laboratory machine, which we appropriately called a spiral- or helical-head chipper was designed, built, and tested (Fig. 12) (4,5). This novel, spiral-head chipper is available for non-exclusive licensing from the U.S. Government (1).

Testing of the Spiral-Head Chipper

The prototype spiral-head chipper was laboratory tested for fingerling particle production from several different small diameter Lake States and Intermountain species. The experimental machine was designed to chip material to about 5 inches in diameter. Evaluations included overall cutter performance, power requirements for spiral-head chipping, and size analysis of the resultant particles. Initial tests revealed this

continuously engaged chipper produced 95 percent or more of the particles to the desired length set by the cutter (Fig. 13). However, since many of the cut pieces were much larger than the target 1-inch by 1-inch cross-section, a means was needed to reduce these oversize chunks to the desired fingerling size. This problem was solved by single-pass feeding of the oversize material through a conventional hammermill with all grates removed (Fig. 14).

The resultant fingerlings were flaked at the Madison Forest Products Lab in a Model PZ-8 Pallman ring flaker. Even though the fingerlings still had considerable cross-section variability, they did orient themselves in the ring flaker so that the knives cut in a plane parallel to the wood grain. (The performance of ring flakes made from spiral-head chipper fingerlings is discussed in a separate paper on flakeboard furnish.)

The power requirement for spiral-head chipping was determined (Table 11) by strain gaging the shaft on which the removable cutter was mounted (Fig. 15). Based on prior crosscut shearing and chipping research conducted at the Forest Engineering Laboratory, the power requirements are related to the specific gravity of the wood, and horsepower requirements can be estimated for other species.

Because of the complexity of fabricating the early cutter heads, certain imperfections resulted which likely added to the basic power requirements. In spite of such fabrication imperfections, the power requirements for producing the fingerling particles are not unreasonably high, but certainly higher than producing conventional wood chips. The spiral-head chipper operates without the benefit of a large flywheel, as do conventional disc chippers, and at a much slower speed. Additionally, because of the basic cutter head design, two to three segments of the spiral cutter are engaged in the sample at one time. All these factors add to the frictional forces involved and total power required.

Based on removal of 2-1/2-inch fingerling particles the theoretical rate of production of spiral-head chipping naturally increases with increases in log diameter and cutter head rpm (Table 12). Although the laboratory spiral-head chipper was operated at only a nominal 50 rpm, it is expected that production units would operate at a rotary speed two to three times this rate.

Comments on Spiral Cutterhead Fabrication

Since this spiral cutter is unique, methods of fabrication are not established. Several cutters were made with each subsequent cutter showing improved

quality and ease of fabrication. To withstand the cutting forces the spiral cutting head must be made with an alloy steel that can be hardened to at least 45 Rockwell C. Although several steel types are suitable, our first spiral cutter was made with boralloy (Paper Calmenson & Co., St. Paul, MN) which gave adequate hardness. However, heat treating and postwelding exaggerated the original plate warpage when the spiral flights were formed. Later cutters were designed with the original plate stock surface ground, welded to a removable sleeve with preheating, and the entire assembly heat treated to the required hardness. This procedure reduced warpage.

Our original spiral cutter was mounted on the shaft by progressively tack welding with the aid of pre-cut spacers of fingerling length. Each spacer was progressively longer than the previous one so as to produce a cutter having a continuously increasing pitch starting from the front of the cutter head. Failure to provide increasing pitch causes the fingerlings to pack in the flights until later cuts eventually force them out. Flight packing is undesirable since it increases friction thereby increasing horsepower requirements. Ideally, the particles are cleared as soon as they are severed.

After only limited operation of the spiral-head cutter with the blade tack welded, failure resulted. Following spot weld failure, the blades were then continuously welded to the shaft which caused excessive warpage. Although the continuous weld resulted in longer cutter-head life, even they eventually failed and needed to be spot repaired.

Although suitable for a laboratory machine, it was recognized that for a woods-portable machine it would not be practical to mount the blade permanently to the drive shaft. Thus, a more practical cutter head design resulted which had the spiral blade mounted on a removable collar. The collar was fabricated with a spiral slot less than the collar thickness, and the blade mounted by essentially screwing it onto the collar and then tack welded. This produced a much better quality cutter head but is still not the ultimate answer to spiral-head chipper fabrication.

A second prototype spiral-head chipper is now being designed which will include an improved spiral cutter that is easier to fabricate and mount. Additionally, the new design will include a means to remove by force the severed particles as they are formed. A low-friction anvil will be incorporated into the design to reduce power requirements. Cutter speed will be increased over the initial prototype as well as diameter of material to be chipped. Future plans are

Table 9. — PRODUCTIVITY AND COSTS FOR HARVESTING OF
HARDWOOD SAWLOG TOPS AND LIMBS

Equipment	Productivity		Study Costs	Est. Cos
	Tops/hr	Green tons/hr	$/Green ton	$/Green
Topwood Processor[1]	14.6[5] (10.5)[6]	10.2 (7.4)	2.25 (3.11)	1.51 (2.
Skidder[2,3]	8.9 (6.7)	6.3 (4.8)	4.38 (5.74)	2.92 (3.
Chipper[4]	25.0 (6.1)	17.5 (4.3)	2.57(10.46)	1.71 (7.
Chainsaw	--	--	0.18	0.18
Total			9.38	6.32

[1] Assumed topwood harvester cost of $45,000 ($23.04/hr)
[2] Skidder cost of $65,000 ($27.57/hr)
[3] Based on average skid distance (round trip) of 1700 ft (830 ft in-woods and 870 ft on skid road).
[4] Chipper cost of $133,000 ($44.98/hr)
[5] At 100% utilization
[6] Includes all delays
[7] Estimated costs data assumes previously recovered pulpwood are recovered with the topwood.

Table 10. -- TOPWOOD PROCESSING TIMES

	No Delays	With All Delays
	----------Min/ton----------	
Topwood harvester	5.9	8.1
Skidder	8.1	10.6
Chipper	3.4	14.0

Table 11. — POWER REQUIREMENTS FOR PRODUCING FINGERLING
CHIPS WITH THE U.S. FOREST SERVICE SPIRAL-HEAD CHIPPER

Species	Samples	SG Range	Specific Pow
	Number		HP-min/FC[3]
Aspen	8	0.343 - 0.377	5.2
Basswood	7	0.278 - 0.318	5.2
Douglas-fir	1	-	8.1
Lodgepole pine	12	0.413 - 0.466	8.7
Larch	8	0.492 - 0.515	9.2
Red oak	6	0.510 - 0.549	9.3
White birch	14	-	9.6
Red maple	5	-	9.8
Sugar maple	3	0.618 - 0.658	15.1

24

Table 12 — FINGERLING PRODUCTION BY OPERATING SPEED
AND LOG DIAMETER

Log Diameter	Cutter Head RPM		
	300	350	400
In.	----------------------Ft^3/min----------------------		
4	5.5	6.5	7.5
6	12.0	14.0	16.0
8	21.5	25.0	28.5
10	34.0	40.0	46.0

to have this improved design built and tested.

Summary and Conclusions

Two primary sources of underutilized North Central States forest resources have the potential to provide substantial amounts of fiber for structural flakeboard: thinning from northern hardwoods and sawlog tops and limbs. By conventional practices, both are normally left in the woods to rot. These wasteful practices and unsightly residues must be eliminated. The traditional reason for leaving this material behind has been the questionable economics related to harvest and transport of thinnings plus tops and limbs.

Forest Engineering Research at Houghton, Michigan, has demonstrated that mechanized thinning of pole-sized northern hardwood can be an effective means of timber stand improvement and permit recovery of the thinned products at a profit. Test trials with mechanized thinning recovered approximately 50 green tons per acre of whole-tree chips at a profit margin of $125 per acre. Conventional chainsaw thinning in Michigan typically costs $25 to $35 per acre and the felled trees are left on the forest floor to rot.

Case studies in residue assessment of hardwood sawlog tops and limbs revealed that about half of the tree is left in the woods after sawlog removal. About 55 percent is greater than 3 inches in diameter. Total residue (all sizes) amounted to an average of 18 green tons per acre. Material greater than 3 inches in diameter was about 10 green tons per acre.

Massive hardwood sawlog tops, if forwarded from stump to landing intact, would likely cause excessive damage to the residual stand--especially during the growing season. A concept developed by the Houghton laboratory is to snip the large protruding limbs with a highly maneuverable, hydraulically-actuated shear, and then align the severed limbs with the main stem of the top. Although

results are preliminary, testing of a prototype topwood processor to prepare large tops in compacted form for grapple skidding to woods landing has shown considerable promise.

Residue tops from a conventional selective sawlog harvest were harvested for slightly under $9.50 per green ton converted to conventional chips, excluding transportation. It is expected that as equipment and techniques--including operator skill--are improved, topwood recovery will become economically more attractive.

Because of existing markets, the system discussed for recovering hardwood thinnings and topwood include converting the product to conventional pulpwood chips. However, conventional chips are unsuitable for structural flakeboard because of the inferior flakes produced from chips. A novel spiral-head chipper has been developed and laboratory tested to reduce small diameter residues to "fingerling" particles that are much more suitable for ring flaking. This Forest Service patented development is available for non-exclusive licensing.

References

1. Barwise, Robert D., Rodger A. Arola, and John R. Erickson. 1977. Helical head comminuting shear. U.S. Patent #4,053,004.

2. Biltonen, Frank E., William Hillstrom, Helmuth M. Steinhilb, and Richard M. Godman. 1976. Mechanized thinning of northern hardwood pole stands: methods and economics. USDA For. Serv. Res. Pap. NC-137. North. Cent. For. Exp. Stn., St. Paul, Minnesota.

3. Dye, Glenn W. 1972. Harvesting hardwood logging residues: an operations and cost analysis. Master's Thesis, Michigan Technological Univ., Houghton, Mich. 106 p.

4. Erickson, John R. 1976. Exploratory trials with a spiral-head chipper to make hardwood "fingerling" chips for ring flakes. For. Prod. J. 26(6):50-53.

5. Gardner, Rulon B., Erwin L. Schaffer, and John R. Erickson. 1978. Converting forest residues to structural flakeboard-- the fingerling concept. USDA For. Serv. Res. Pap. INT-200. Intermountain For. and Range Exp. Stn., Ogden, Utah.

6. Heebink, B.G. 1972. How and when-- structural particleboard from forest residue. USDA For. Serv., For. Prod. Lab., Madison, Wisconsin. 9 p.

7. Heebink, B.G. 1972. Some views on large structural particleboard panels USDA For. Serv. Res. Note FPL-0220, For. Prod. Lab., Madison, Wisconsin. 8 p.

8. Hesterberg, Gene A. 1957. Deterioration of sugar maple following logging damage. USDA For. Serv. Stn. Pap. 51, For. Exp. Stn., St. Paul, Minnesota. 58 p.

9. Mattson, James A., and Eugene M. Carpenter. 1976. Logging residue in a northern hardwood timber sale. North. Logger and Timber Process. 24(7):16-17,29.

10. Quigley, Kenneth L., and James T. Morgan. 1969. Sugar maple timber re sources. In Sugar Maple Conf. Proc., Michigan Technological Univ., Houghto Mich. [Aug. 20-22, 1968.]

11. Steinhilb, H.M., and Glenn W. Dye 1973. Harvesting logging residue fro selectively cut northern hardwood sta North. Logger and Timber Process. 21(11):12-14, 34-37.

12. Steinhilb, Helmuth M., and Sharon Winsauer. 1976. Sugar maple: tree bole weights, volumes, centers of gra and logging residue. USDA For. Serv. Pap. NC-132. North Cent. For. Exp. S St. Paul, Minnesota. 7 p.

13. Stone, Douglas M. 1977. Fertili and thinning northern hardwoods in th Lake States. USDA For. Serv. Res. Pa NC-141. North Cent. For. Exp. Stn., St. Paul, Minnesota. 7 p.

14. U.S. Department of Agriculture, F Service. 1973. The outlook for timb the United States. Forest Resource R 20, U.S. Dep. Agric., Washington, D.C 367 p.

Figure 1.-(A) Typical northern hardwood poletimber stand.
(B) Logging residues following conventional chain saw thinning.
(C) Thinning with a mechanical feller buncher with accumulating head.
(D) Poletimber stand after mechanized shelterwood thinning.
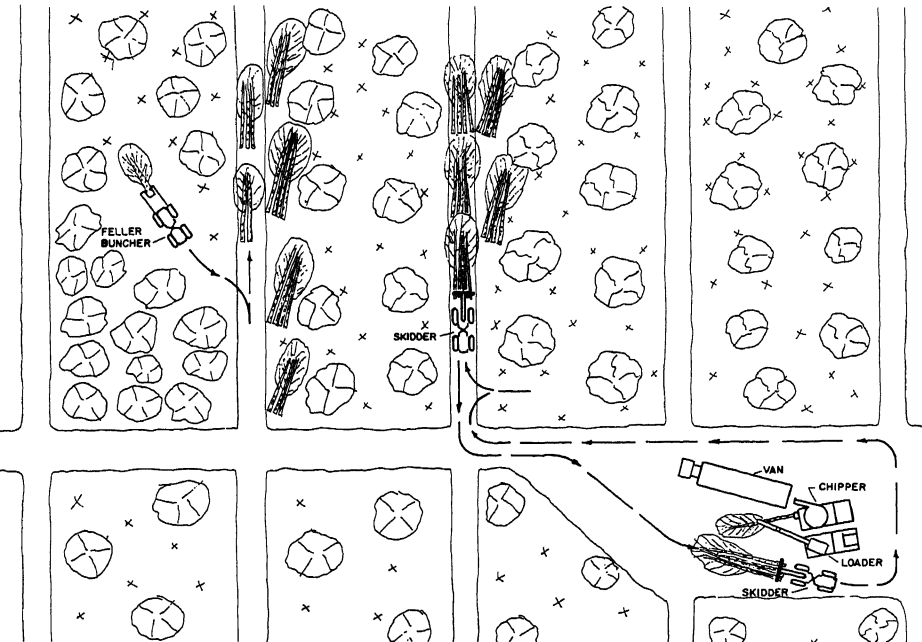
Figure 2.--Strip with selective thinning
        in leave strip
        (A) Simplified schematic of
            system.
        (B) Pre-bunched trees ready
            for grapple skidding.

Figure 3.--Break-even analysis of
        mechanized thinning (2).

**PROFIT AND LOSS BASED ON THE
MEAN PRODUCTIVITY FOR ENTIRE THINNING**

27
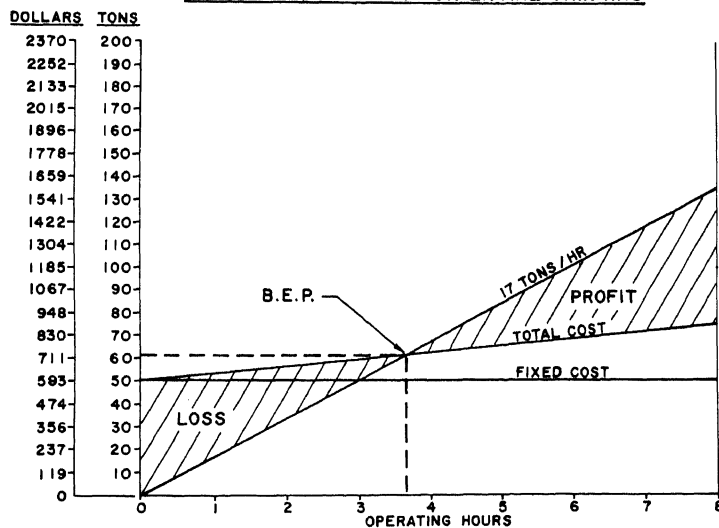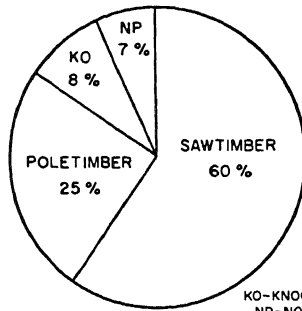
(A) TOTAL RESIDUE
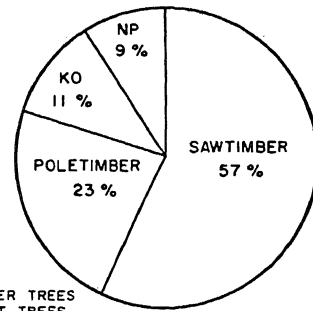
(B) RESIDUE >3" DIA.

NOTE:
KO—KNOCKED OVER TREES
NP—NO PRODUCT TREES
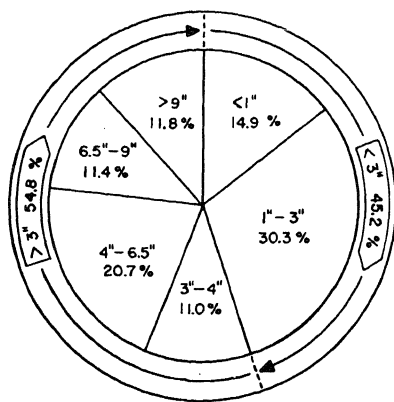
(C) SAWTIMBER TREES
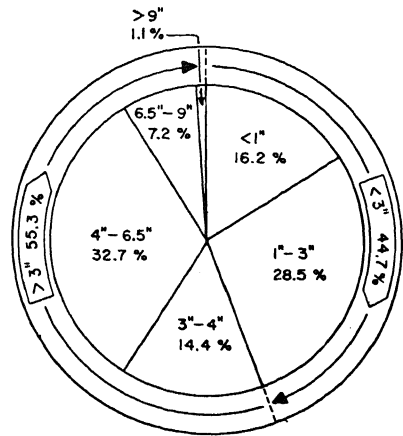
(D) POLETIMBER TREES

Figure 4.—Source and size breakdown of residual tops and limbs following a northern hardwood sawlog timber sale (9).

RESIDUE WEIGHT = 383.7 + 3.569(DBH)^2

S.E.E. = 1.604 (dbh)^2

RESIDUE WEIGHT/MBF = 84195.8 — 7957.6(DBH) + 201.4(DBH)^2

S.E.E. = 4,134.7
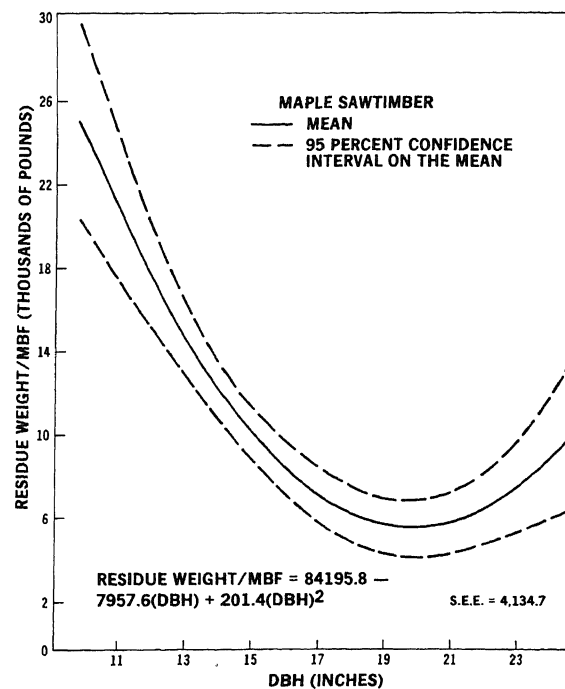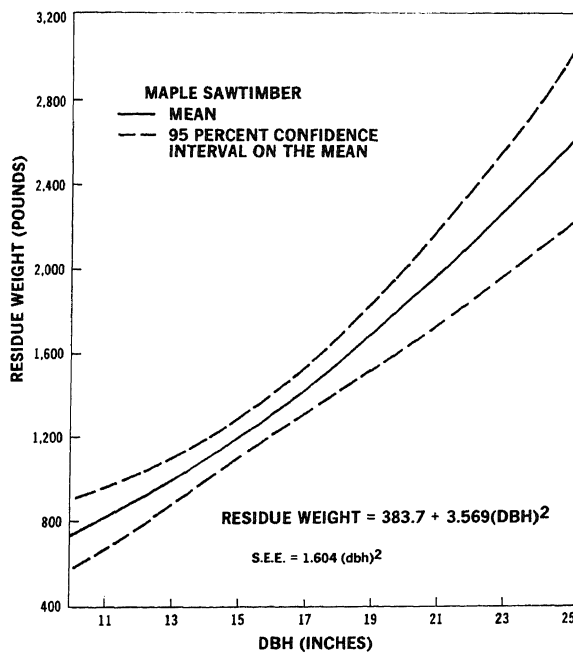
Figure 5.—Variation of residue in sugar maple sawtimber trees (12).
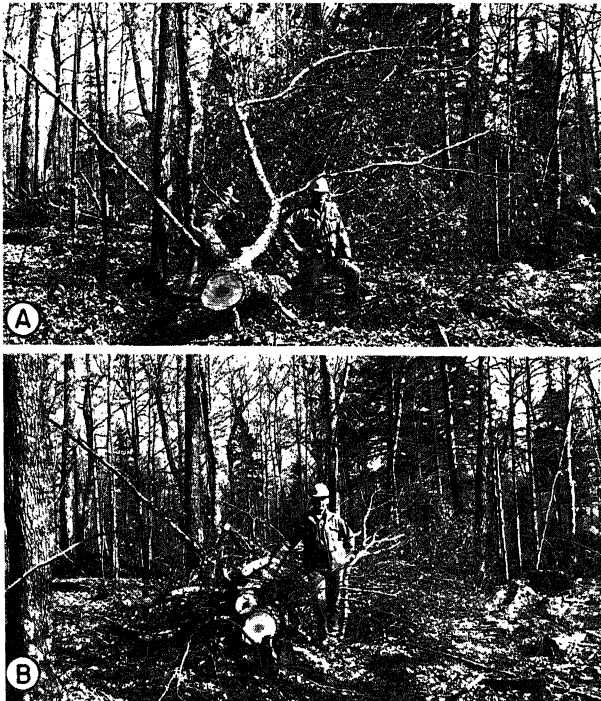
Figure 6.-In-woods preparation of hardwood sawtimber tops for forwarding. (A) Typical hardwood sawlog top. (B) Compacted top.
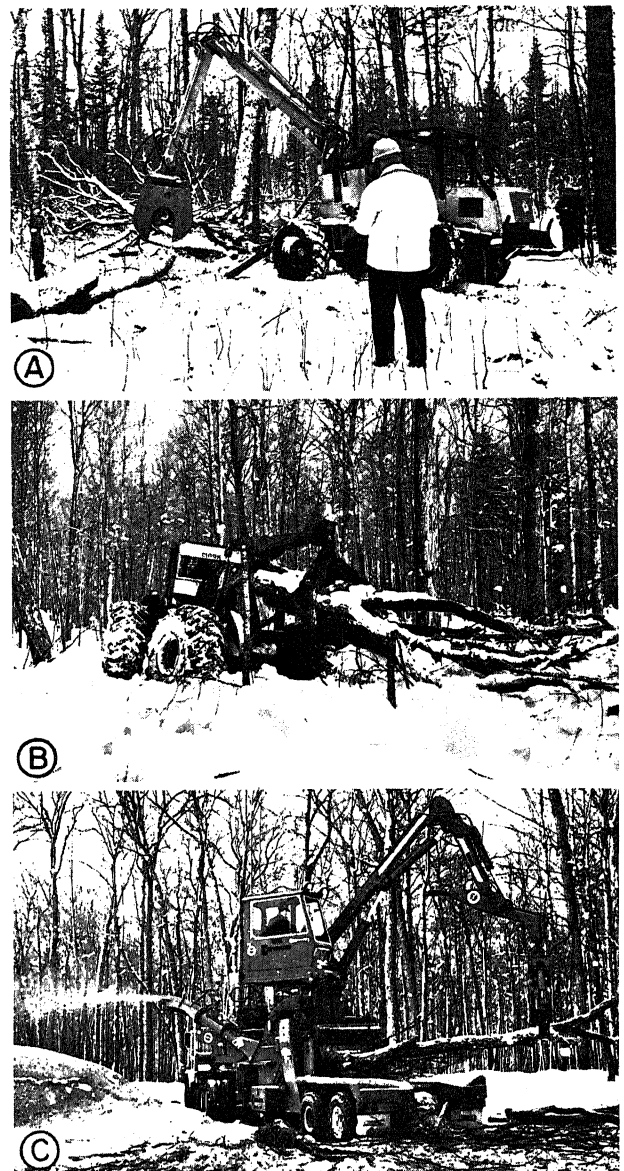
Figure 7.-Field trials with mechanized topwood recovery. (A) Experimental topwood processor. (B) Grapple skidding of processed top. (C) Conventional chipping of recovered topwood.

Figure 8.-Experimental topwood harvester processing a sawlog top.
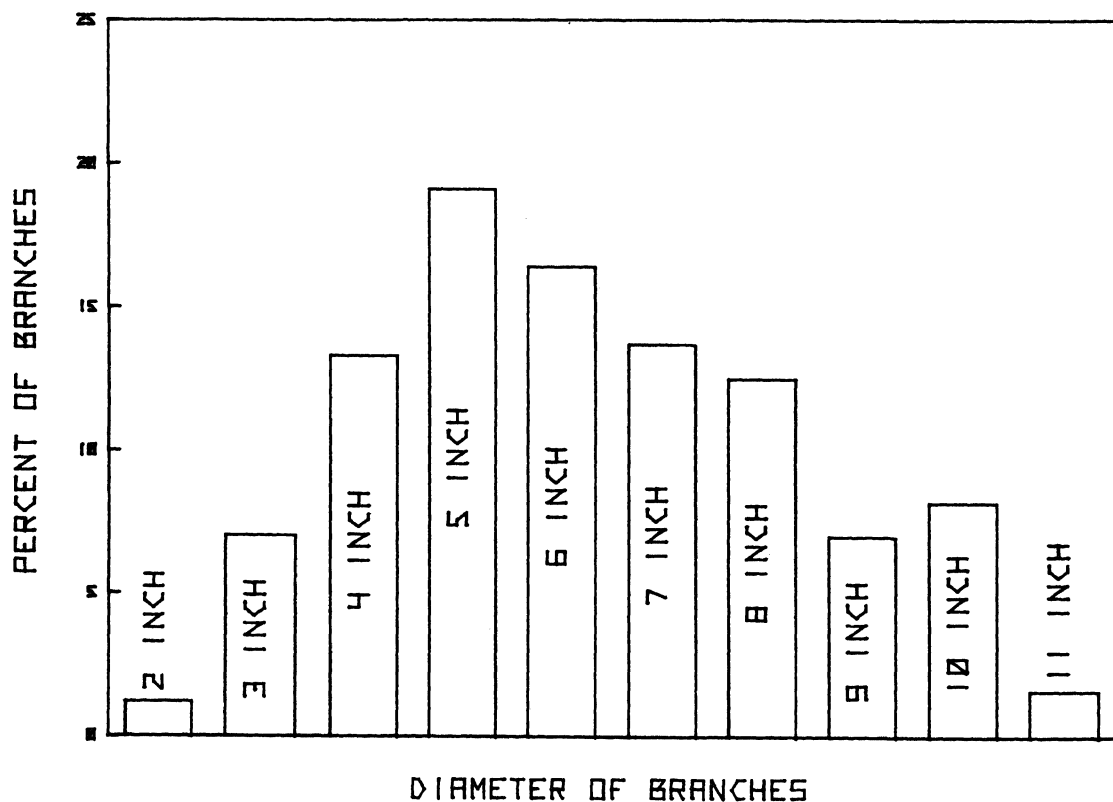
Figure 10.--Summary of topwood processing data--size
of limbs severed.
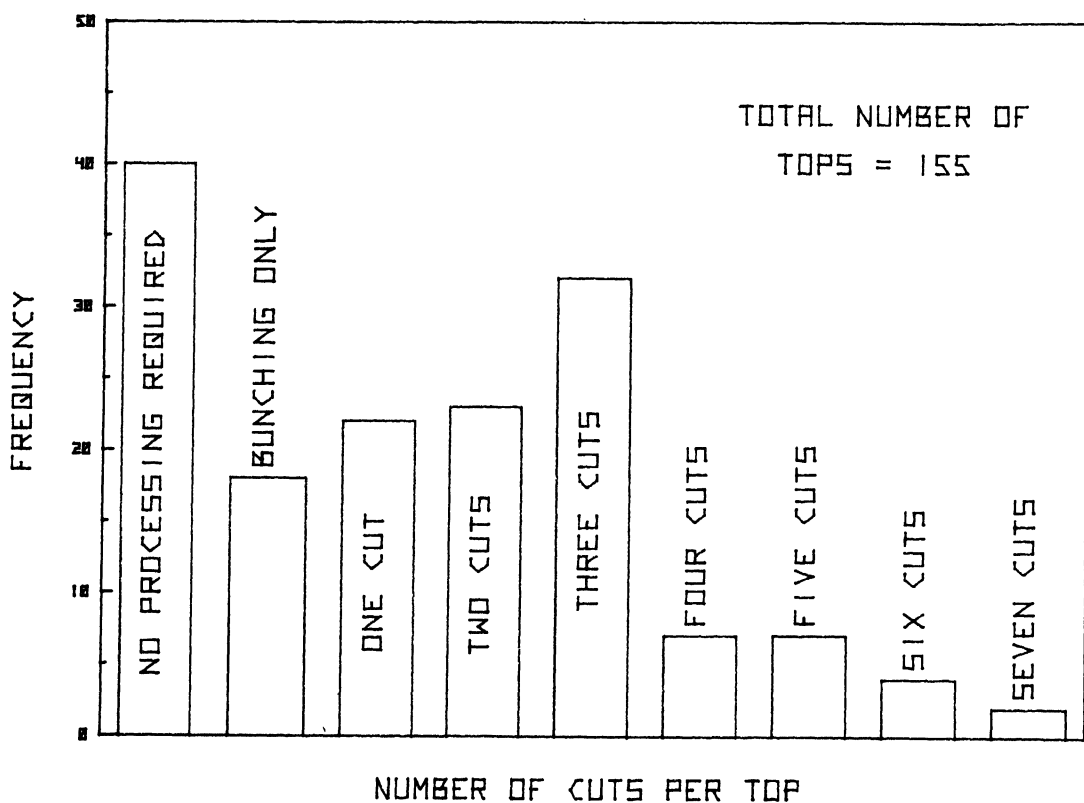
Figure 9.--Summary of topwood processing data--number
of limbs severed per top.
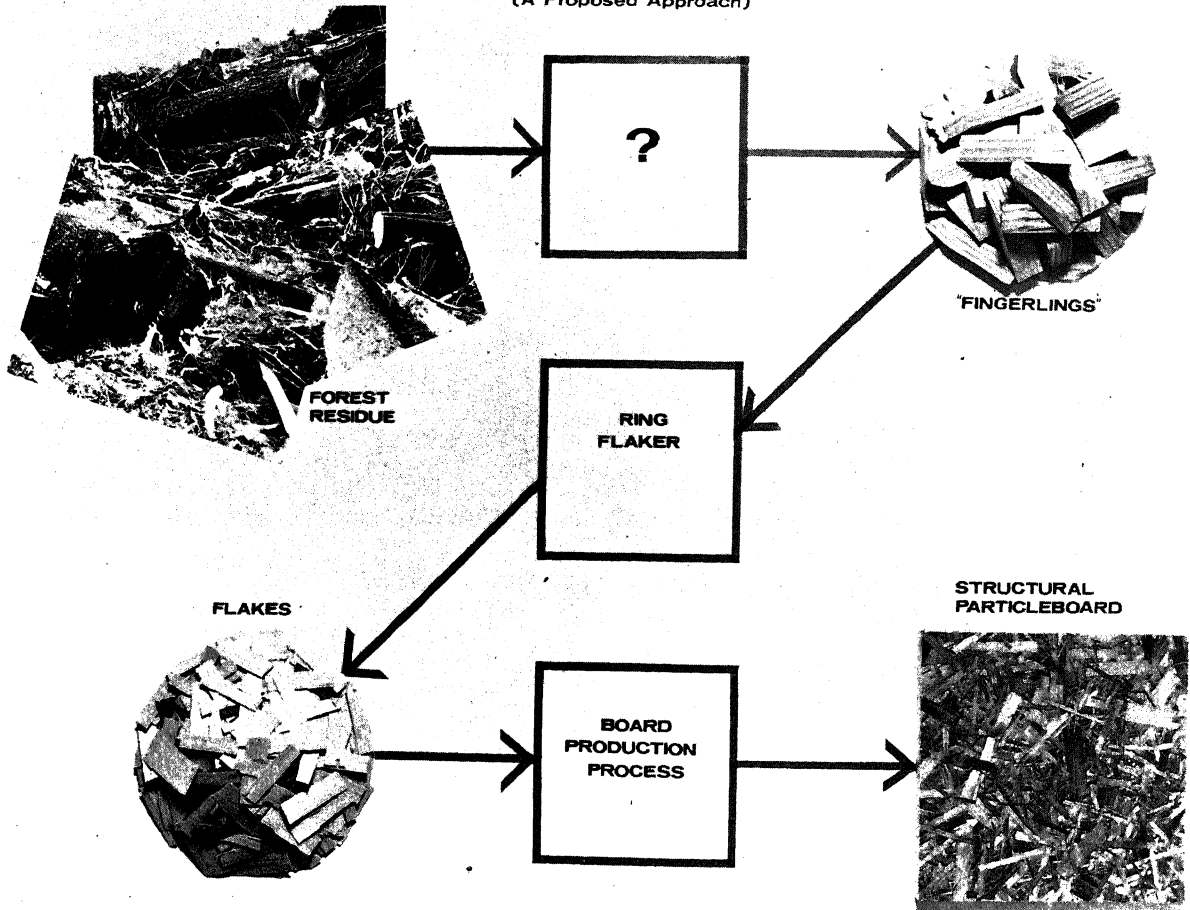
Figure 11.--"Fingerling" approach to using forest residues in structural flakeboard.
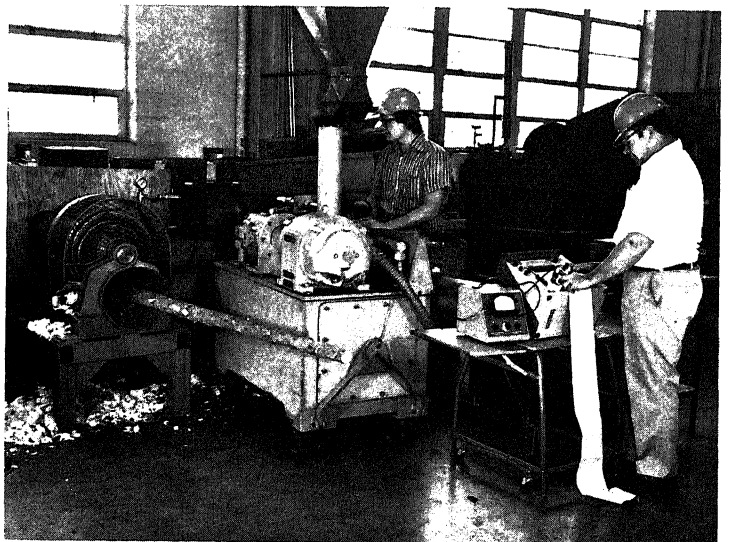
Figure 12.--Laboratory testing of experimental spiral-head chipper.

Figure 13.-- Screened red maple particles cut with spiral-head chipper.
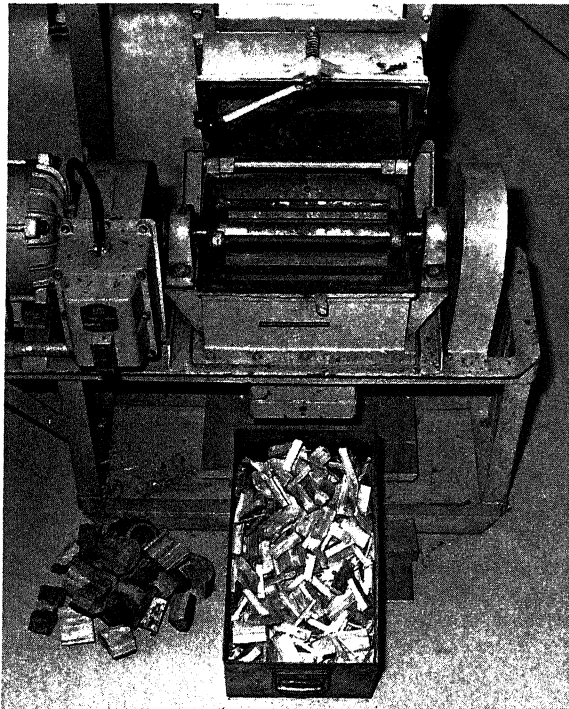
Figure 14.--Reduction of oversized spiral-head chipper particles to figerlings by subsequent hammermilling.
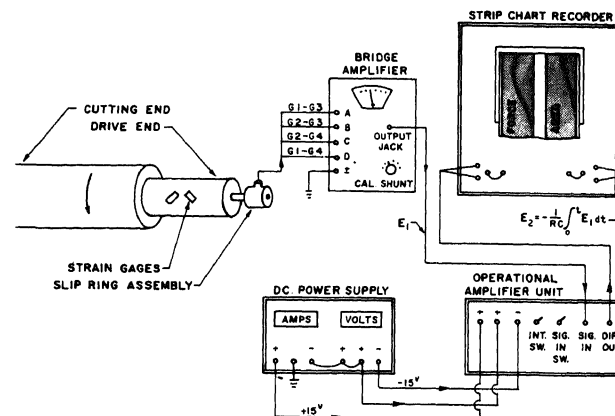
Figure 15.--Schematic of instrumentation to determine power requirements to produce fingerling chips with U.S. Forest Service spiral-head chipper.

STRUCTURAL FLAKEBOARD: COLLECTION, TRANSPORTATION, AND
PREPARATION OF WESTERN FOREST RESIDUES

David P. Lowery[1]
Wood Technologist

John R. Host[1]
Research Forester

Intermountain Forest and Range Experiment Station
USDA Forest Service
Ogden, Utah

Abstract

Despite sporadic attempts at utiliza-
tion, huge quantities of forest residues
remain unused in the western United
States. Structural grade flakeboard has
been experimentally manufactured from
residues, but costs, particularly the
harvesting and processing of residues,
render the product noncompetitive with
plywood. Improved harvesting and proces-
sing equipment may soon improve the
economic feasibility of converting
residues to structural flakeboard.

Introduction

In the western United States, forest
residue is defined as wood left on an
area after logging, thinning, road
building or clearing operations and fire,
disease, and insect killed timber. This
includes tops, unmerchantable trees,
broken pieces, and dead or defective logs.
The residue generated on a particular
area by forestry activities can be af-
fected by the terrain, site, vegetative
type, aspect, species, harvesting system,
equipment, and the sales agreement. The
quantity of residue can affect the
economics of utilizing this material.

Because of the newness of the concept,
very little work has been done on forest
residues as a raw material for structural
flakeboard. Research studies have been
made on their use for pulp and paper
manufacture, conventional particleboard,
and as a fuel source. It is assumed that
much of the information developed in
these studies would be transferable to
a structural flakeboard industry. Table
1 shows that there is an abundant supply
of forest residues on the large National
Forest acreage in the West. The cost of
collecting, transporting, and processing
this material has been the major con-
straint on its utilization.

Although, at the present time, dis-
posing of forest residue is a problem, the
potential structural flakeboard manu-
facturer should know that other segments
of the forest products industry have used
or have looked at the possibilities of
utilizing all or portions of this waste.
During the pulp chip shortage of 1973 and
1974, many paper companies chipped forest
residues. Also, public and private
research facilities have studied the use
of residues as fuel and as a potential
source of chemicals. All of these uses
appear uneconomical under present condi-

tions. However, as equipment manufacturers
develop new processing machinery, the use
of forest residues will undoubtedly in-
crease.

This report reviews the status of
forest residues in the western United
States--quantities available, attempts at
intensive utilization, harvesting and
processing equipment and costs, and poten-
tial products. Although other uses are
not ruled out, feasibility of converting
residues to structural grade flakeboard
received special emphasis. For conveni-
ence the West has been divided into three
areas and each area is discussed
separately.

Southern Rocky Mountains

The principal timber species of this
area are ponderosa pine, Douglas-fir,
lodgepole pine, Engelmann spruce, and the
true firs. The dryer, lower elevation
sites are occupied by ponderosa pine. The
other species grow at the higher elevations
which are more inaccessible and costly to
harvest. Aesthetic and biological
considerations require the most of the
region's timber stands be harvested
selectively and this harvesting system
usually results in dispersal of the forest
residues over extensive areas, table 1.

In 1974, Sampson and others (6), pub-
lished an evaluation of inwoods chipping in
the Four Corners area comprised of Arizona,
New Mexico, Colorado, and Utah. The
objective of this study was to determine the
possibility of producing pulp chips from
unmerchantable trees and from residues
usually left in the woods. The study
trees were felled, limbed, and bucked with
chain saws and skidded with rubber-tired
or tracked skidders. A Nicholson Logger
Model Utilizer was used to debark and chip
the material at the landing. The pulp
chips were blown into a chip van for
transport to either a reload station or to
a pulp mill.

The results of this evaluation showed
that timber utilization was improved (the
minimum diameter processed through the
debarker was 3 inches), the environmental

_____

[1]Stationed at the Intermountain
Station's Forestry Sciences Laboratory in
Missoula, Montana.

Table 1. — ACREAGE CUTOVER, VOLUME HARVESTED, AND QUANTITY OF
RESIDUE GENERATED ANNUALLY ON NATIONAL FORESTS IN THE WESTERN REGIONS[1]

| Region | States | Estimated Annual Harvest | | |
		Acreage	Volume	Residues
			Million bd. ft.	Thousand tons
1	N. Idaho Montana	110,000	1,200.0	5,500.0
2	Colorado Wyoming South Dakota	74,000	315.0	750.0
3	Arizona New Mexico	209,191	401.5	1,000.0
4	Nevada Utah S. Idaho	53,000	437.0	1,800.0
5	California	150,000	1,900.0	15,000.0
6	Oregon Washington	600,000	4,500.0	24,000.0

[1]Personal communication with timber management and fire control personnel in the
various regional offices.

quality of the harvested areas was not
impaired, and that high-quality chips
were produced. Unit cost of producing
chips in the woods was substantially
greater than for chips produced at a
mill.

The total cost of producing chips by
this procedure was estimated to range
from $25 to $30 per ovendry ton. Trans-
portation costs increased these values
to $42 to $60. The report stated that
these costs would probably decrease as
the operating crew became more pro-
ficient and as the equipment was modified
to better conform to the field conditions.

Northern Rocky Mountains

The mixed timber stands of this area are
composed primarily of Douglas-fir, western
larch, pines, firs, and spruce. Because of
current and post insect epidemics, the
region contains large quantities of dead
timber, principally lodgepole pine. The
dead timber, presently underutilized, is
a resource that could be used as raw
material for a structural flakeboard
industry. In addition, the forest residue
from harvesting is relatively concentrated,
although the mountainous terrain usually
requires specialized and sometimes costly
harvesting equipment. The following
discussion describes commercial and research
attempts to use forest residue for pulp and
fuel chips.

During the pulp chip shortage of
1973, a commercial operator in north
Idaho used 2 Melroe Bobcat feller-
bunchers, 2 Timberjack 360 grapple skid-
ders, and a Morbank 75 chipper to clear-
cut lodgepole pine stands on Federal

lands and partially cut mixed stands
State lands. This was a multiproduc
operation in that stud logs were als
obtained. The average diameter of t
trees removed was 5.5 to 6.0 inches
d.b.h. and the volume removed, 20 to
cords per acre.

The procedure followed was to fe
and skid about three days in advance
chipping. The feller-bunchers sorte
trees when felled. Smaller trees we
bunched for skidding to one landing a
the larger trees, from which saw log
stud logs could be cut, were bunched
skidding to a second landing located
short distance from the first. After
logs had been cut and decked, the top
were pulled to the first landing.

All the material accumulated at
first landing was chipped without de-
barking. The stem-wood chips were bl
into a van for transportion to a mill
and the branch and foliage chips were
blown into a separate pile for dispos
either by burning or by spreading ove
the harvested area.

This system proved to be most ef
ficient. Approximately 1,000 stems p
shift were cut and skidded about 660
Chip production averaged 8 to 10 load
11 to 12 units per trailer each shift

The pulp mill receiving these ch
reported no processing problems, alth
as the chip supply from mill refuse b
more abundant, the pulp mill required
screening and bark removal. The deli
price for these chips was about $33 p
ovendry ton.

A major forest products company in the Northern Rocky Mountains has also investigated the possibility of utilizing forest residues for pulp chips and as fuel. In one study, an old-growth stand was clearcut and a mixed-age stand was partially cut. Production in ovendry tons per acre is shown in the following tabulation:

Old-growth

Saw logs	Pulp logs	Residue
46	23	24
49%	25%	26%

Mixed-age

Saw logs	Pulp logs	Residue
32	11	5
68%	23%	9%

The equipment used in this study consisted of a Drott feller-buncher, chain saw, to fell the oversized trees, two Cat 518 rubber-tired grapple skidders, a bulldozer (part-time) and a 17- or 22-inch chipper. The material chipped included unmerchantable trees, tops (branches, needles, and stems), chunks broken from the stem, and small cull or pulp logs made when bucking for saw logs.

A second study, using the same equipment, determined the cost of removing different quantities of logs and chips from four study areas. The results of this determination are shown in Table 2. As would be expected, the higher volume and value of the logs reduces the delivered cost at the mill of the combined logs and chips removed from the areas. The production of chips only, increase the cost from $0.81 to $4.79 per oven-dry ton above the cost of producing logs and chips. The cost was also affected by the harvesting method used; the clear-cutting regime had lower delivered costs than the partial cuts. At an assumed production rate of 100 ovendry tons per day, whole tree chipping cost was calculated to be $22.34 per ovendry ton.

A second phase of the study was concerned with the cost of disposing of logging slash piles by chipping. A crane, chainsaw, and chipper were used in this study part. The average cost of the delivered chips was $70.83 per ovendry ton. This high cost reflects the inefficient use of the machinery. The projected cost of producing an assumed 100 ovendry tons per day of this type of material for fuel was $18.20 per ovendry ton.

Another relevant study was conducted by the Intermountain Forest and Range Experiment Station in western Montana.

A three-man crew, Melroe Bobcat, grapple skidder, two chain saws, and a chipper were used to thin and remove insect-infested trees from an 80-year old ponderosa pine stand. Felling and bunching was completed a few days prior to the start of skidding. The grapple skidder pulled the trees to a landing where house and stud logs were cut from the stems. Tops and smaller trees were chipped and the chips hauled to a pulp mill. The chips proved unsuitable for pulp but suitable for fuel. Delivered cost of the chips was not meaningful because this was a family-type operation.

In addition to inwoods chipping, condefective logs and trees have been concentrated and trucked to either a pulp mill or to a satellite chipping station in the Northern Rockies. This endeavor also dates back to the pulp chip shortage of 1973 and 1974 and has subsequently been stopped. Much of the timber salvaged for chips was obtained from timber sales where green logs had been harvested and from dead timber located close to roadsides. No special equipment was used to harvest these cull logs. More than 150 million board feet of logs were purchased during a two-year interval. Costs ranged from $50 to $65 MBF or $25 to $33 per cord (5).

Pacific Northwest

The Pacific Northwest area is usually divided into western and eastern sections, with the Cascade Mountains as the boundary. The western portion of the region contains many large, overmature stands of Douglas-fir. When these stands are harvested, tremendous tonnages of forest residue consisting of cull logs, dead trees, tops, and unmerchantable trees remain. The average gross weight of bone dry tons per acre has been estimated to be 57 tons (2). The eastern portion contains smaller size timber, with ponderosa pine and lodgepole pine the principal species. The average tonnage of forest residue remaining in these stands after harvesting has been estimated to be about 35 tons per acre.

In the western portion, the steep mountainous terrain and large timber requires the use of cable harvesting systems and heavy logging equipment. Here the limitations of the chipping and hauling equipment preclude the processing of forest residue in the wood. An alternative method that has been developed is the yarding of unutilized material (YUM). In this method, the timber sales agreement requires the yarding of the forest residue to a landing for later disposal. Although the method was originally intended to facilitate disposal by burning, utilization opportunities may be enhanced by concentrating the residue at roadside.

The major advantage of the YUM system is that the cost of yarding the low-value,

Table 2. — QUANTITY AND COST OF REMOVING SAW LOGS AND CHIPS FROM FOUR STUDY AREAS IN THE NORTHERN ROCKIES USING DIFFERENT HARVESTING REGIMES

| | Quantity Harvested | | | | Delivered Cost at Mill | |
| | Total | | Per acre | | | |
Cutting Regime	Logs & chips	Chips only	Logs & chips	Chips only	Logs & chips	Chips only
	----------------ODT-----------------				--------$--------	
Leave trees 9"	302	241	15.1	12.0	34.35	39.1
Leave trees 6"	529	502	22.0	21.0	32.71	33.6
Clearcut	480	461	22.0	21.0	28.58	29.3
Sanitation cut (insects)	1,198	1,008	29.6	25.0	27.72	31.7

low-quality material is included in developing the sales appraisal. The cost of moving this material to roadside is then borne by the good logs that are harvested.

Another procedure that has been developed and used to a limited extent in this area is termed PAM (per acre material). In timber sales of this type the purchaser pays for the green or sound logs at a fixed price per thousand board feet, log scale, by species. The large cull and small sound logs on the sale area, which contain below a given net volume, such as 80 board feet, would be purchased for a lump sum per acre (3).

Timber sales of the PAM type tend to encourage the operator to remove all the material that will pay for its handling and hauling costs.

East of the Cascades, timber size, terrain, and forest residue are similar to that encountered in the Northern Rocky Mountain region. Hence, the collection procedures for forest residues that have been developed and used are similar to those described under the preceding section of this report. Fellerbunchers and grapple skidders are commonly used harvesting equipment.

A recent innovation has been use of the Hahn harvester at the landing. With this machine, trees are skidded to the landing intact and fed into the harvester. The machine then delimbs and bucks the tree to the desired length or top diameter. An attachment for the harvester is being developed that will chip the branches and unused top and make this available either for fuel or for pulp.

Transportation of Forest Residues

Historically, two methods have been used for transporting forest residues: 1) where chipping is performed at the harvesting site, chip vans are used, and 2) where chipping is done at the manufacturing plant or reload station, trucks and trailers transport the material in the round.

Two sizes of chip vans are commonly used in the west; a 40-foot van with a capacity of 38,000 pounds and a 45-foot van with a capacity of 42,000 pounds. The 40-foot van is preferred for inwoods chipping because of its greater maneuverability on forest roads. For maximum efficiency, it is necessary that the material to be chipped be concentrated a a landing prior to the chipper being operated. Also, it would be desirable to have two or three chip vans being located at the landing for loading. A single tractor could then be used to pull the loaded vans to the mill or rail road siding and return the empty vans for reloading.

The average daily production using 17-inch chipper with this system is abou 10 rows, depending on the haul distance.

Because of the many factors involved, such as hauling distance and turnaround time, it is difficult to estimate the exact cost of chip transportation. Withycombe (7) has estimated this cost to be 5 cents per hig way-ton-mile. However, because of the increased care and time required for forest roads, this cost should probably be at least doubled and possibly tripled.

Logging trucks and trailers have been used to transport forest residues in the log form. This equipment has a load capacity of approximately 52,000 pounds or about 5,000 board feet, log scale. The trucks, designed and built for woods hauling, are usually individually loaded at the landing. The forest turnaround time may be fairly lor depending on the size and number of pieces loaded.

The cost of hauling forest residue by this system would be essentially the same as for higher valued green logs destined for lumber or plywood. At thi time, the average hauling cost, forest to mill, is about $10 to $15 per thousa board feet, log scale.

Flakeboard Manufacture

Pulp chips are not suitable for the manufacture of structural flakeboard. Heebink (4) has stated that flakes for structural flakeboard should be fairly long and thin. In his experimental work he was able to produce 2-inch-long and 0.02-inch-thick flakes by first reducing log bolts to pieces termed "fingerling." Fingerlings were approximately 2 to 3 inches long and 3/4 to 1 inch in cross-sectional area. Fingerlings were produced in a modified drum chipper, then the fingerlings were flaked through a ring flaker.

Using the fingerling method, wood residues could be debarked and made into fingerlings in the forest. The fingerlings would be transported to the plant by chip van, processed into flakes, and formed into structural board panels.

An alternative would be to transport the residue in the round to the plant site. Here debarking or cleaning the logs, sawing to optimum length, and processing through the fingerling chipper and flaker could be accomplished.

In either event, the cost of producing suitable flakes would exceed the cost of producing pulp chips.

A recently published report by Gardner (1) provides detailed information on the production of fingerlings in the woods. A simulation program was used to evaluate six different harvesting systems, including a cable yarding system. The results indicated that five of the systems could deliver fingerlings to a flakeboard mill for approximately $25 to $33 per ovendry ton. The increased yarding cost of the cable system resulted in a delivered mill cost of about $43 per ovendry ton.

Summary

Enormous quantities of forest residues are generated annually on the National Forests of the western United States. The principal areas of concentration of this material are the Pacific Northwest, California, and the Northern Rocky Mountains. At this time, the collection, transportation, and preparation of forest residues for structural flakeboard manufacture appears to be uneconomical. However, equipment and procedures for precessing residues more efficiently are being developed, and the prospects for its increased utilization seem promising.

Within the last few years, research has used two methods to improve the utilization of forest residues. One method has been complete tree harvesting in which the entire tree is brought to a landing and after the more valuable stem wood has been removed the top foliage and branches are chipped. Unmerchantable wood is also chipped at the landing. This method has proved suitable for making pulp chips at times when such chips are in short supply. The method might also lend itself to the production of fingerlings that are then flaked for structural flakeboard.

The second research method has been the removal of selected portions of the forest residue, primarily cull and dead tree logs, to an off-forest site. At this location, the residue logs have been made into pulp chips and could be made into fingerlings. In the Pacific Northwest the traditional sales agreement has been modified to require the yarding of unutilized material (YUM) or a fixed price per acre has been charged for the material (PAM). Forest residues would then be available for use in structural flakeboard.

Although both methods appear promising, the present economic situation is the major constraint. Recent studies indicate that the costs of collecting and transporting forest residue have a range from about $30 to $60 per ovendry ton. These costs far exceed the costs of material from alternative supply sources, sawmills and planing mills. However, new harvesting equipment and systems may reduce the costs associated with forest residue and increase the utilization of this material by all wood using industries, including structural flakeboard.

Technology is presently available for transporting and processing forest residue into structural flakeboard. Chip vans and logging trucks can be used to transport this material and modified drum chippers can produce fingerlings for processing in a ring flaker.

Structural flakeboard is a definite possibility for utilizing the tremendous quantities of forest residues available in the West.

References

1. Gardner, R.B., E.L. Schaffer, and J.R. Erickson. 1978. Converting forest residue to structural flakeboard--the fingerling concept. USDA For. Serv. Res. Pap. INT-200. Intermt. For. and Range Exp. Stn., Ogden, Ut.

2. Grantham, J.B. 1974. Status of timber utilization on the Pacific Coast. USDA For. Serv. Gen. Tech. Rep. PNW-29. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

3. Hamilton, T.E., J.O. Howard, and T.C. Adams. 1975. Per-acre pricing--its effect on logging residue. USDA For. Serv. Res. Pap. PNW-192. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

4. Heebink, B.G., E.L. Schaffer, J. Chern, and J.H. Haskell. 1977. Structural flakeboards using ring flakes from fingerling chips. USDA For. Serv. Res. Pap. FPL 296. For. Prod. Lab., Madison, Wis.

5. McMichael, M.D. 1975. 5D wood--a viable fiber resource. Proc. 30th Northwest Wood Products Clinic. Wash. State Univ., Pullman.

6. Sampson, G.R., H.E. Worth, and D.M. Donnelly. 1974. Demonstration of in-woods pulp chip production in the Four Corners region. USDA For. Serv. Res. Pap. RM-125. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

7. Withycombe, R. 1975. The outlook for particleboard in the Northern Rocky Mountain Region. USDA For. Serv. Gen. Tech. Rep. INT-21. Intermt. For. and Range Exp. Stn., Ogden, Ut.

TWO METHODS OF ACQUIRING RESIDUAL WOOD FOR SOUTHERN FLAKEBOARD PLANTS: THE SHAPING-LATHE HEADRIG AND THE MOBILE CHIPPER

Peter Koch [1]
Chief Wood Scientist
Southern Forest Experiment Station
USDA Forest Service
New Orleans, Louisiana

Abstract

With little disburbance of existing southern wood markets, structural flakeboard plants with annual capacities of 7.5 to 150 MMSF, 1/2-inch, can be supplied from hardwoods growing on southern pine sites. One sawmill equipped with a 9-foot shaping-lathe headrig (or three 54-inch shaping lathes) and a salvage roundwood flaker can furnish enough flakes to produce 37.5 MMSF of flakeboard annually. Use of three mobile chippers to retrieve logging residues can double wood recovery so that residual flakes and chips are sufficient for a flakeboard plant with annual capacity of 75 MMSF 1/2-inch. A sawmill with one 9-foot shaping lathe, three 54-inch shaping lathes, and six mobile chippers could supply flakes and chips for annual production of 150 MMSF, 1/2-inch. On rough or rocky terrain, skidders and roadside chippers would replace mobile chippers. Clean flakes and chips provided the flakeboard plants by these systems would be priced about the same as pulpwood chips of the same species.

Introduction

Plants that manufacture structural flakeboard from southern woods offer substantial opportunity for profit; it is likely, therefore, that from 1980 to 1990 several such manufacturing facilities will be constructed. Annual plant capacities will probably range from 37.5 to 150 MMSF, 1/2-inch basis. This paper describes two processes by which wood can be obtained for these plants without greatly upsetting existing wood markets in the South.

If made from a mixture of southern species (mostly hardwoods) structural flakeboard weight at shipment will be about 50 pounds per MSF, 1/2-inch. Therefore, plants will require 37,500 to 150,000 tons of dry flakes annually.

Moisture content of stemwood in pine-site hardwoods ranges from a low of 47 percent in green ash to a high of 120 percent in sweetgum. Average moisture content of stemwood from these hardwoods, weighted by the percentages in which they occur, is about 75 percent (dry-weight basis). A ton of dry flakes can therefore be obtained from 1.75 tons of green wood. Accordingly, green wood requirement of the proposed flakeboard plants will range from 66,000 to 263,000 tons annually, depending on plant capacity.

Delivered wood in the form of green flakes, chips, or roundwood should cost the plant $12 to $30 per ton on a dry weight basis, $7 to $17 per ton on a green weight basis, or $21 to $51 per cord on a volume basis. Plants can operate most economically on a 100-percent-flake furnish, and least economically on barky roundwood, assuming that flakes, chips, and roundwood are all available at the same price per ton and at the same moisture content.

Because the structure of the hardwood roundwood (i.e., pulpwood) business in the South is well understood, harvesting and delivery techniques for this product will not be further discussed. Instead, this paper concentrates on methods of obtaining residual flakes from other manufacturing operations and on methods to harvest logging residuals with a mobile chipper. Economics of roadside chippers will not be analyzed, because their operation is understood by the industry.

Residual Flakes from the Shaping-Lathe Headrig

In the South, the major underused wood resource is hardwoods on pine sites. In stemwood of trees 5 inches d.bh. and larger, there is about 0.8 ton of these hardwoods for every ton of pine on southern pine sites. About half of this hardwood volume is in trees 5.0 to 10.9 inches d.b.h.; the other half of the volume is about evenly divided between trees 11.0 to 14.9 inches d.b.h. and those 15.0 inches and larger (7).

These hardwoods are of low quality, frequently have short and crooked stems, and contain varying amounts of rot introduced by fire scars, branch stubs, or bird and insect damage. Today, a significant--perhaps major--portion of these hardwoods is unused or destroyed during site preparation for establishment of southern pine.

The shaping-lathe headrig is a new machine designed to convert short logs from such low-quality trees into cross-ties or posts, cants for resawing, or cylindrical bolts to be rotary peeled. Residue from the headrig is flakes of

uniform length and thickness. These residual flakes (Fig. 1) which can be produced in any thickness from 0.010 to 0.030 inch, are excellent--perhaps the best available--furnish for structural flakeboard manufacture (8).

The headrig is available in three models:

- A pallet-cant machine that converts logs 5 to 12 inches in diameter and 40 to 53 inches in length to cants for resawing into pallet deck boards and stringers (Fig. 2).
- A post, crosstie, and cant machine that converts logs 6 to 9 feet long and 5 to 15 inches in diameter into highway posts, half-ties, full-size ties, or cants for resawing (Fig. 3).
- A roundup machine that converts 8-1/2-foot long bolts up to 30 inches in diameter into the largest perfect cylinders within such logs; these cylinders can be subsequently peeled into continuous veneer (Fig. 4).

To simplify discussion, only the 9-foot headrig (Fig. 3) will be analyzed to assess its ability to provide flakes for the proposed flakeboard plants and a variety of rough green or air-dry products for different markets.

For the industrial market, the headrig can provide: cants to be resawn into pallet or container shook; light timbers to 9 feet in length; industrial blocking of odd cross-section, e.g., round, hexagonal, or octagonal; and hexagonal cants to be crosscut into industrial block flooring.

For the railroad and highway market, the headrig can provide: one piece crossties and dowel-laminated crossties to 9 feet in length (Fig. 5) and highway posts (round or square) in lengths from 4-1/2 to 9 feet.

For the customer market (via retail yards), the headrig can provide: fence post (4-1/2 to 9 feet long), fence rails (6 to 9 feet long), cants for resawing into 8-foot studs or 4 x 4's, cabin logs, and architectural crossties for use in landscaping.

For the furniture market, the headrig can provide: cants in 6- to 9-foot lengths for conversion to furniture dimension stock, rounded-up veneer bolts or cants for slicing, and crosstie side lumber.

To keep the flakeboard plant operating at full capacity, the headrig should run 3 shifts a day, 5 days a week, 48 weeks of the year. Because about 25 percent of wood volume received on the saw-

mill's merchandising deck will be too crooked, rotten, small, or large for processing through the shaping lathe, this portion will go directly to a dis[c] or drum flaker. Both shaping-lathe he[ad]rig and salvage roundwood flaker make some fines; as much as 5 percent of al[l] flakes may be screened out for use as fuel and will not be available to the flakeboard plant.

Since the total flake requirement the smallest flakeboard plant would amount to 37,500 tons (dry) annually, sawmill must produce 164 tons (dry) of flakes daily, i.e.,

$$\frac{37,500}{240}/0.95.$$

Of this amount, 75 percent (123 tons) will come from the shaping lathe, and percent (41 tons) will come from the salvage roundwood flaker.

Log shapes and likely machining pa[t]terns indicate that the shaping lathe will probably produce equal weights of flakes and cants. Daily input of bark free logs to the shaping lathe will therefore need to be about 246 tons on dry weight basis, 430 tons on a green weight basis, or about 13,500 cubic fe[et] per day. This amounts to 4,500 cubic feet of logs per 8-hour shift.

The shaping-lathe headrig is desig[ned] to machine 1,440 logs per shift into cants, i.e., four logs per minute for 360 minutes of each shift. If 1,440 logs are to contain 4,500 cubic feet o[f] wood, each log must average 3.13 cubic feet. If logs processed average 92 inches long, they need to average abou[t] 8.7 inches in mid-length diameter to contain 3.13 cubic feet. This average diameter is about right for a mill pro[ducing half ties (Fig. 3 top, Fig 5), highway posts, and cants for resawing (Fig. 3 bottom).

Accordingly, one 9-foot shaping-lathe headrig and one salvage roundwoo[d] flaker will easily supply the wood for plant producing 37.5 MMSF, 1/2-inch fl[ake]board annually. The price at which fl[akes] are transferred from lumber mill to fl[ake]board plant might be about the same as of pulp chips of the same species mix. (See references (3,4) for estimates of cost of such a sawmill).

Loggers might harvest about 4,500 acres per year of southern forests stocked with low-grade hardwoods to ge[t] the logs required, i.e., 1,440 logs pe[r] shift averaging 92 inches long and 8.7 inches in diameter at mid-length. Thi[s] would call for land that contained abo[ut] 88 trees per acre averaging 20 feet of merchantable stem usable on the headri[g].

If the land available had too few

logs of 8.7-inch diameter, but had smaller bolt wood averaging 6.5 inches in diameter, and 40 to 53 inches long, then three 54-inch machines designed to make pallet cants (Fig. 2) should be used in place of the 9-foot shaping lathe.

Mobile Chipper

Since the flakeboards discussed in this paper have 3 layers it is possible to use flakes of low quality in the core and save the best flakes (e.g., those from a shaping-lathe headrig or round-wood flaker) for face material. A low-cost source of core flakes is large pulp chips (maxi-chips) processed through a ring flaker.

While such chips might be purchased, I propose to get them by harvesting cull trees and logging slash with a mobile chipper (Fig. 6). Chips (Fig. 7) would then be split 30:70 between fuel (fines and barky chips) and appropriately sized mostly bark-free chips to be ring-flaked for core material.

Three mobile chippers with associated equipment (Fig. 6) should recover 90,000 tons (green basis) of chips annually, 70 percent of which would be suitable for core material (63,000 tons on a green basis or 36,000 tons on a dry basis). Hardwood residue harvested in this fashion should cost about $14 per green ton delivered to the flakeboard plant, or $24,50 per dry ton (6). Each machine should annually traverse about 1,500 acres containing heavy logging slash and many standing culls.

The 27,000 tons (green) annually of fuel is enough to fire four burners continuously, each producing 5.5 million Btu hourly (Fig. 8; see also (5)).

Accordingly, a flakeboard plant producing 75 MMSF, 1/2-inch flakeboard annually and requiring 75,000 tons (dry basis) of wood could be supplied by residues from a sawmill equipped with one 9-foot shaping-lathe headrig (or three 54-inch headrigs) and from logging slash recovered from 4,500 acres per year by three mobile chippers. Plants of larger annual capacity, e.g., 150 MMSF, 1/2-inch, could obtain one 9-foot shaping-lathe headrig, three 54-inch shaping lathes, and six mobile chippers that recover logging residues and cull trees from about 9,000 acres per year.

Mobile chippers (Fig. 8) will be operable on, for example, south Georgia terrain or along the Texas-Louisiana border, but they will not be practical on steep rocky slopes such as those in West Virginia or northern Arkansas. In these areas, it would be more economical to skid residues to roadside chippers.

References

1. Howe, J.P. and P. Koch. 1976. Dowel-laminated crossties--performance in service, technology for fabrication, and future promise. For. Prod. J. 26(5):23-30.

2. Koch, P. 1975. Shaping-lathe headrig now commercially available. South. Lumberman 231(2896):93-97.

3. Koch, P. 1976. Making dowel-laminated crossties with the shaping-lathe headrig--it should be profitable. South Lumberman 233(2896):82-83.

4. Koch, P. and R.A. Caughey. 1978. Shaping-lathe headrig can profitably yield solid-wood and molded-flake products from mixed hardwoods. For. Prod. J. (In press)

5. Koch, P., L.F. Day, and M.T. Jasper. 1978. A new suspension burner for green bark and hogged fuel. In Proc. Symp., "Complete-tree utilization of southern pine", C.W. McMillin, ed. For. Prod. Res. Soc., Madison, Wis. (In press)

6. Koch, P. and T.W. Nicholson. 1978. Harvesting above-ground residual biomass and swathe-felling with a mobile chipper. In Proc. Symp., "Complete-tree utilization of southern pine", C.W. McMillin, ed. For. Prod. Res. Soc., Madison, Wis. (In press)

7. Murphy, P.A. and H.A. Knight. 1974. Hardwood resources on southern pine sites. For. Prod. J. 24(7):13-16.

8. Price, E.W. and W.F. Lehmann. 1978. Flakeboard properties as affected by flake fabrication techniques. For. Prod. J. (In press)

9. Springate, N.C. 1978. Economic prospects for southern manufacture of composite structural sheathing with flake core and veneer faces. In Proc. Symp., "Complete-tree utilization of southern pine", C.W. McMillin, ed. For. Prod. Res. Soc., Madison, Wis. (In press)

10. Springate, N.C., I. Plough, and P. Koch. 1978. Shaping-lathe roundup machine is key to profitable manufacture of composite sheathing in Massachusetts or Maine. For. Prod. J. (In press)
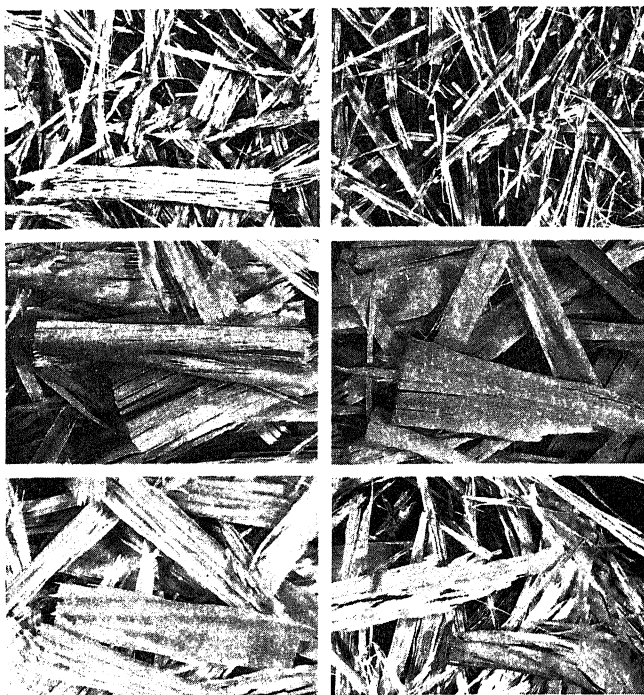
Figure 1.--Face flakes 0.015 inch thick and 3 inches long in
random widths produced on the shaping lathe. Top left,
white oak (Quercus alba L.); top right, southern red
oak (Quercus falcata Michx.); center left, hickory
(Carya spp.); center right, sweetgum (Liquidambar
styraciflua L.); bottom left, southern pine; and bottom
right, the five species mixed.
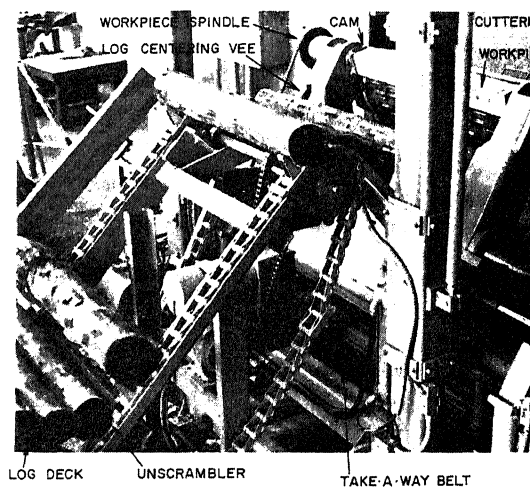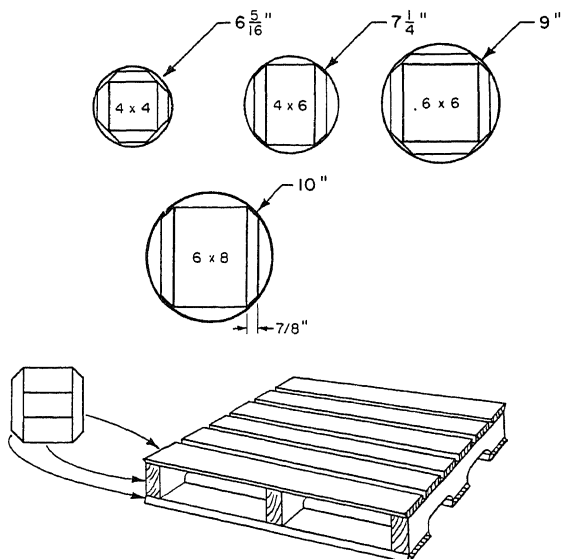
Figure 2.--(Right) Shaping-lathe headrig for manufacture of pallet
cants can handle logs 40 to 53 inches long and 4 to 12
inches in diamater. Key elements (arrows) are: lower
left, log deck and unscrambler; upper left, log cen-
tering vee and workpiece spindle; center top, cam;
upper right, workpiece, cutterhead and charger; lower
center, take-away belt. (Left) Cants from headrig
can be sawn into deckboards and stringers for pallets (2).
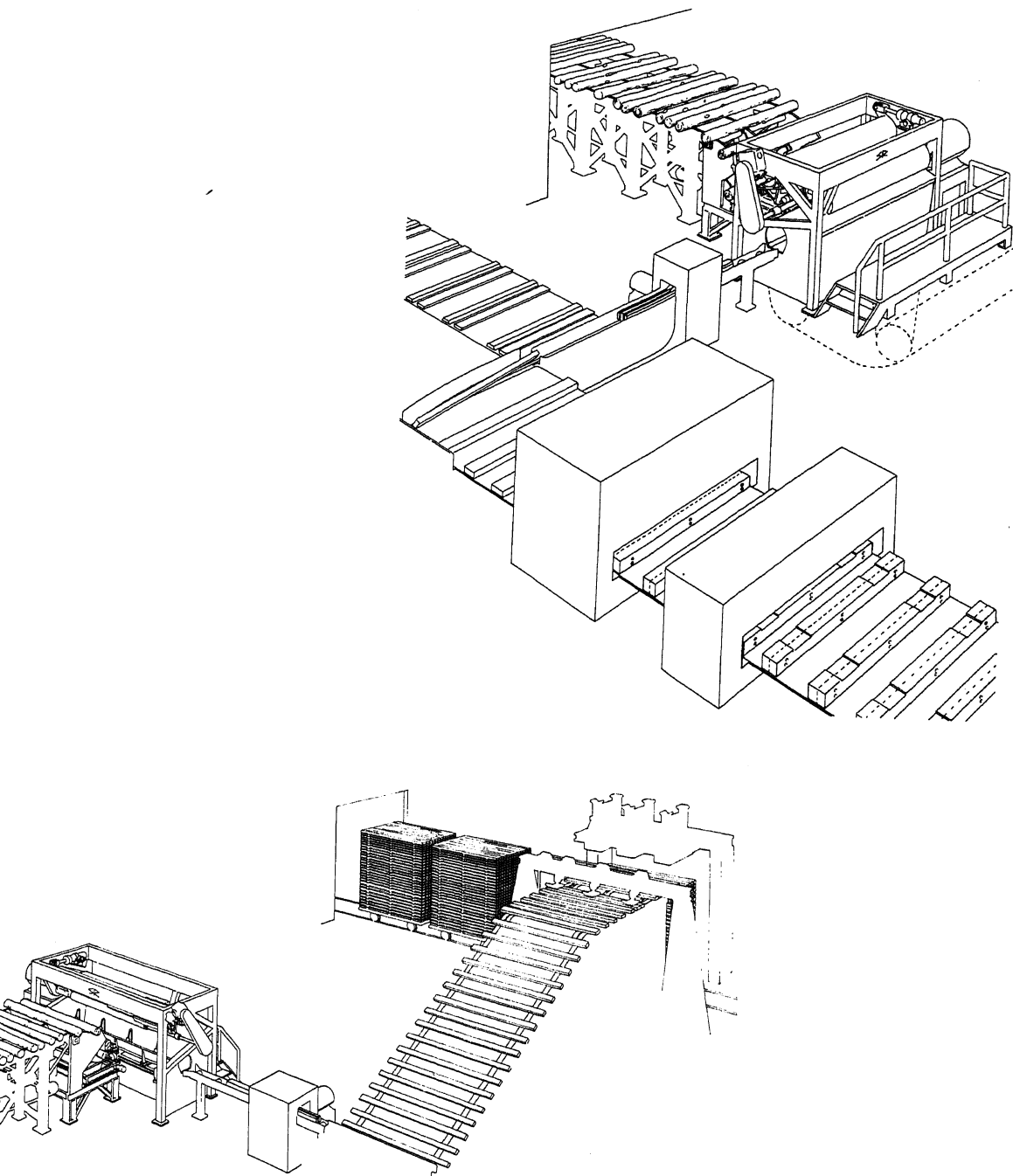
Figure 3.--Shaping-lathe headrig for logs 6 to 9 feet long and 5
to 15 inches in diameter. The headrig yields cylindrical,
octagonal, and hexagonal shapes as well as rectangular
or square. (Top) Mill layout for production of doweled
crossties and side lumber. (Bottom) Mill layout for
cants to be resawn into lumber, e.g., studs.
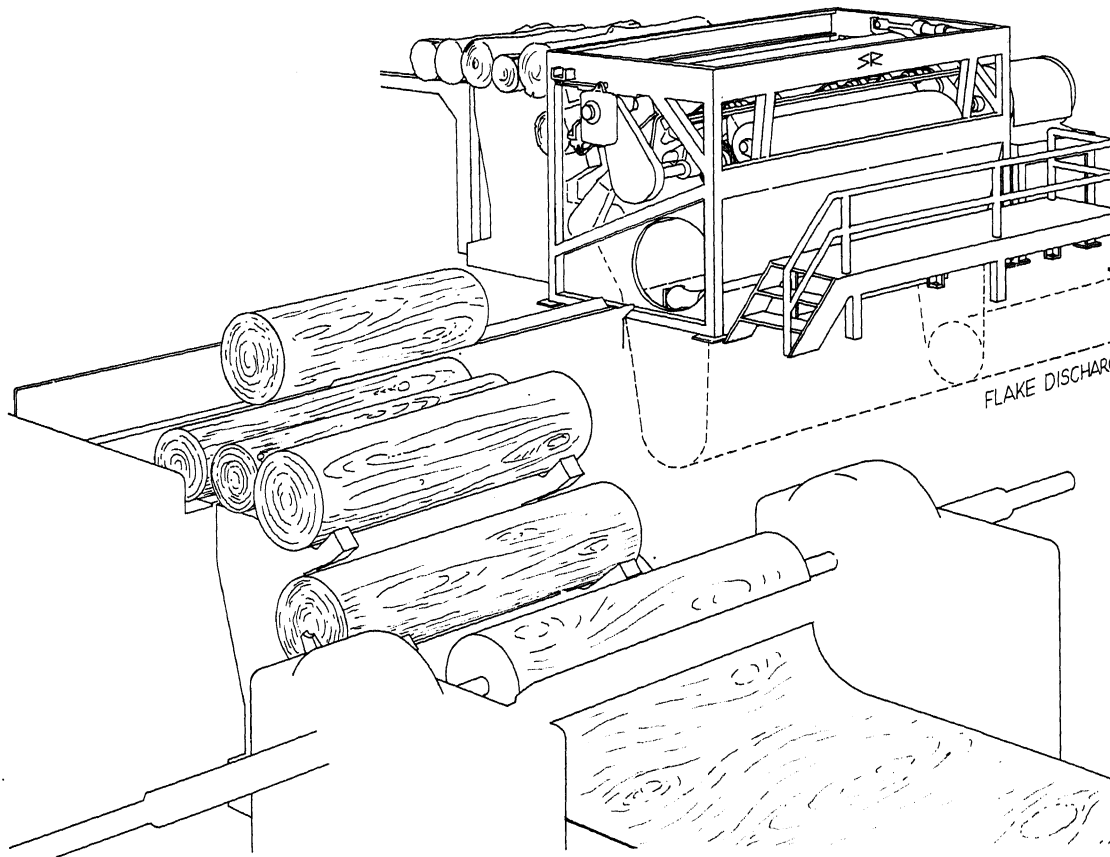
Figure 4.--Roundup-shaping-lathe to produce flakes and cylindrical peeler bolts yielding continuous veneer from logs 8-1/2 feet long and up to 30 inches in diameter. For a description of this operation see references (9,10).
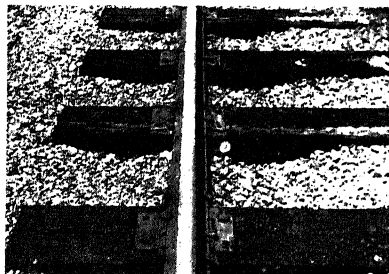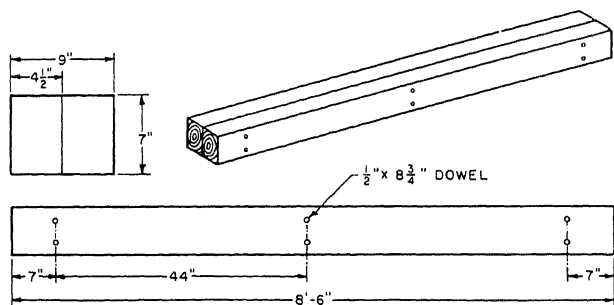
Figure 5.--(Top) Dowel-laminated crosstie secured with three pairs of 1/2-inch spirally fluted steel dowels. No adhesive used. (Bottom) These steel-doweled mainline ties have been made from logs 8.5 inches in diameter, a size in plentiful supply (1).

CHIP DISCHARGE

14'- 10 1/2"
FOR DISCHARGE

TREE PUSHER
BAR

575 HP
DIESEL ENGINE

FEED RAKE

11'- 6"
FOR TRAVEL

OIL PAN

2.0" MIN. GROUND
CLEARANCE

20' - 6-1/2"

7.0" NOMINAL
GROUND CLEARANCE

26'- 1" OVERALL

GROUND CLEARANCE BASED ON 2" TRACK PENETRATION

47.5 CHIPPER
SPOUT WIDTH

7'- 9 1/2" FELLER BAR

9'- 2"
OVERALL
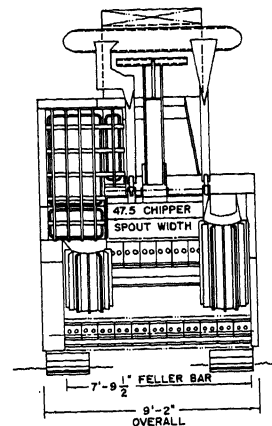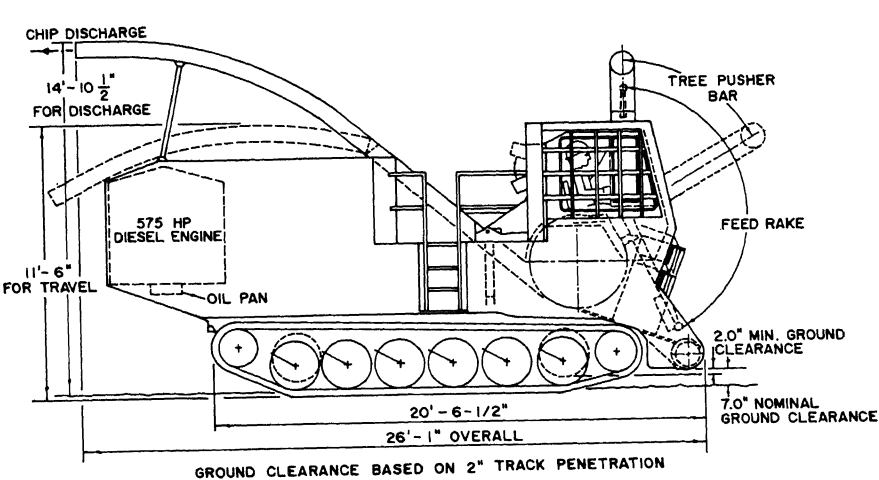
Figure 6.--Mobile chipper for retrieval of cull trees and logging
residues. (Top) Prototype machine. (Bottom) Three
machine team capable of traversing an acre an hour and
delivering chips into roadside inventory piles (6).
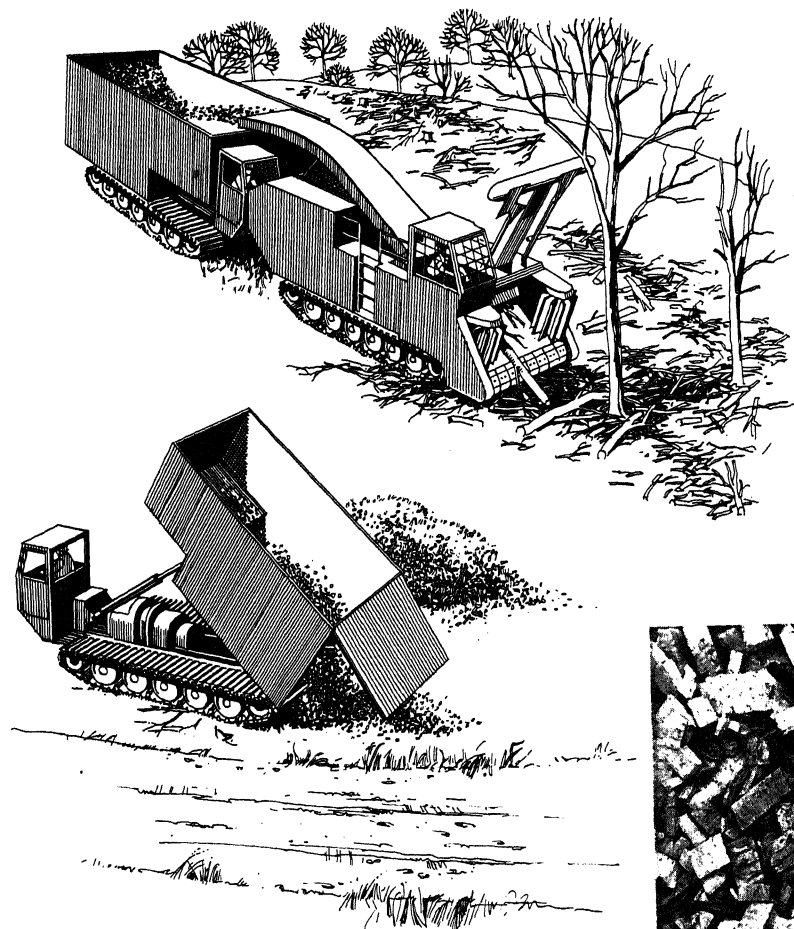
Figure 7.-- Chips from prototype mobile chipper measure about 1 inch
long. Feed design could be modified to attain longer
lengths if required.

GREEN FUEL IN

CYCLONE

AIR LOCK

SCREW DRIVE MOTOR (DC)

BINDICATOR

CONE

ELEV. 22'-7 5/8"

BARK HOPPER AIR PRESSURE SUPPLY

COMBUSTION AIR IN

DAMPER

HOT STACK GAS OUT

22"ø

SHEATH TUBE 27" O.D.

COMBUSTION AIR PRE-HEATER

COMBUSTION ZONE

COMBUSTION AIR AT 700° F

UPPER OUTER SHELL

FEED SCREW

FUEL BEING DRIED

TAPER OUTER SHELL

LOWER OUTER SHELL

STRUCTURAL SUPT

HEARTH SECTION

AUXILLIARY GAS BURNER

ELEV. 0

22-1/2"

11"

3'-0"

7'-0"

3'-0"

8'-1"

8'-0"

Figure 8.--Suspension burner for hogged green wood or bark. Exiting hot exhaust gas can directly heat kiln, or can heat a boiler to produce steam for process use

FLAKING ALTERNATIVES

Eddie W. Price [1]
Wood Scientist
Southern Forest Experiment Station
USDA Forest Service
New Orleans, Louisiana

William F. Lehmann [2]
Weyerhaeuser Company
Tacoma, Washington

Abstract

Three-layer structural flakeboards were prepared at two densities and two resin contents (5 and 8 percent) from flakes cut on a shaping-lathe headrig and on disk, drum, and ring flakers. Panels were made from lodgepole pine (Pinus contorta Dougl.), loblolly pine (Pinus taeda L.), sweetgum (Liquidambar styraciflua L.), southern red oak (Quercus falcata Michx.), and mockernut hickory (Carya tomentosa Nutt.).

The ring flaker produced 23.78 percent fines; the drum, lathe, and disk produced only 7.7, 3.5, and 2.2 percent fines. Of the flakes used for panel fabrication, i.e., those retained on 1/16-inch and larger screens, lathe- and disk-cut flakes had the lowest specific surface and therefore most resin applied per thousand square feet of flake surface area.

Flakes averaged about 2.25 inches long (except ring-cut oak and hickory flakes, which were slightly shorter). Flakes were slightly less than 0.02-inch thick (except for disk-cut flakes which were slightly thicker).

When panels of the low-density species (lodgepole and loblolly pines and sweetgum) were analyzed, bending strength, modulus of elasticity, internal bond, linear expansion, and thickness swell were all strongly influenced by interactions of main factors (flaker, species, resin content, and compression ratio). Such interactions would not allow simple comparisons of the main factors. Flaker types were therefore compared over a range of compression ratios for each individual species of wood. Lodgepole pine boards had highest bending strength and modulus of elasticity when made from lathe-cut flakes, and highest internal bond strength when made from ring-cut flakes. The flake-type yielding least linear expansion and thickness swell varied with conditioning cycle (24-hour water soak, 30 to 90 percent RH, or ovendry vacuum-pressure soak).

Loblolly pine boards made at low compression ratios were strongest and stiffest if made from disk-cut flakes; at high compression ratios lathe-cut flakes made boards of highest bending strength and modulus of elasticity. Internal bond strength of loblolly pine boards was highest when made from ring-cut flakes, but boards made from lathe-cut flakes had most stability.

At high compression ratios, sweetgum panels had highest bending strength and modulus of elasticity when made from disk-cut flakes but highest internal bond strength when made from ring-cut flakes. Sweetgum boards were most stable when fabricated from lathe-cut flakes.

At any compression ratio from 1.20 to 1.50, lodgepole pine boards generally had lowest modulus of rupture, modulus of elasticity, and internal bond strength. Loblolly pine and sweetgum boards often had similar properties.

When oak and hickory boards were evaluated, those made from lathe-cut flakes had highest bending strength and stiffness. Increasing resin content from 5 to 8 percent improved bending properties; the degree of improvement was affected by species and flaker type. Internal bond strength was highest in boards made of ring-cut flakes and was greatly influenced by resin content and species. Linear-expansion values were low in panels of drum-cut flakes pressed to high compression ratios and for boards of lathe-cut flakes at low compression ratios. Thickness swell of oak and hickory boards was inversely correlated with resin content. Most properties of red oak flakeboards of 52.6 pcf density were superior to hickory boards of this density but were inferior at equivalent compression ratios.

Overall, use of disk and lathe flakers yielded boards with higher bending strength and modulus of elasticity for initial test conditions (50 percent RH) and after accelerated aging. Internal bond strength of boards made of ring-cut flakes (132 psi) was the highest. Despite their higher internal bond strengths, boards made of ring-cut and drum-cut flakes were less stable after being subjected to environmental conditioning than boards made from lathe- and disk-cut flakes. In general, species with higher wood densities had higher measured property values. Also, the higher density species generally had a larger percent loss in properties after aging.

[1] Stationed at Pineville, La.

[2] Formerly Technologist, Forest Products Laboratory, Madison, Wis.

Introduction

Logging residue from many regions is being evaluated by the Forest Service to provide technical data on the feasibility of using such residue in structural sheathing. Western residues are mostly from softwoods; small, cull, low-grade hardwoods comprise the residue from the South. Development of a structural panel utilizing the western residue has been the concern of the Forest Products Laboratory (FPL). The Southern Forest Experiment Station (SO) has concentrated on the southern residue. Each laboratory has recommended three-layer panels, but differences in flakes and particles have dictated different layering and particle geometries.

At least four types of commercial machines exist for producing the large quantities of flakes required for structural flakeboards: the disk, drum, and ring flakers and the shaping-lathe headrig. The objective of this study was to determine the characteristics of structural flakeboards made from flakes produced by each of these machines.

Results of a screen analysis are given in Part I. Part II analyzes the properties of panels made from sweetgum, lodgepole pine, and loblolly pine (low-density species) and fabricated at compression ratios (ratio of panel density to species density) of 1.25 and 1.50. Part III reports the properties of red oak and hickory panels fabricated at a compression ratio (CR) of 1.25, and at a second CR such that the density of the panels was 52.6 pcf. In Part IV, major factors--resin content, species, and flakers--are discussed in attempting to decide which flaker is best overall. which flaker is best overall.

Procedure

Small-diameter bolts (about 7 inches) of sweetgum (Liquidambar styraciflua L.), red oak (Quercus falcata Michx.), mockernut hickory (Carya tomentosa Nutt.), and loblolly pine (Pinus taeda L.) were obtained in central Louisiana. Small-diameter lodgepole pine (Pinus contorta Dougl.) logs were obtained in Colorado and shipped to Louisiana. Material of each species was randomly divided for flaking with a disk flaker located at FPL, ring flaker at FPL, shaping-lathe at SO, or drum flaker at Washington State University. Before flaking, all material was debarked by hand. The flakers were calibrated to produce flakes 2.25 inches long, 0.020 inch thick, and random width. Bolts to be flaked with the ring flaker were first chipped in a drum chipper that produced chips 2.50 inches long and then flaked. The shaping-lathe employed circular cams decreasing at the rate of 1 inch per revolution down to a 4-inch diameter.

The drum flaker feeding mechanism pivo through a small angle.

Lathe flakes were dried to less th 10 percent moisture content and shippe FPL. Drum flakes were shipped green to with a small amount of formaldehyde add to inhibit mildew and fungus contamina Before panel fabrication, all flakes we dried to about 3 percent moisture conte and screened through 2-, 1-, 1/2-, 1/4- 1/8-, and 1/16-inch screens. The mater that passed through the 1/16-inch scree was discarded after the percentage of total weight that it composed was calcu lated. Accepted flakes were divided in equal weight fractions of large and sm flakes; three-layer boards were constr with the small flakes in the core and flakes equally divided between face layers.

For each species and flaker combi tion, two panel replications were fabr cated for each of two resin contents (. 8 percent based on ovendry weight of flakes) and two densities. For all sp a panel density was established at a CI of 1.25. Additional flakeboards of sw gum and both pines were made at a CR o 1.50. Additional oak and hickory boar were pressed to 52.6 pcf.

Board Manufacture

Panel manufacturing conditions we

Panel size: 1/2 in. by 24 in. by 28 in.
Binder: Phenol-formaldehyde li resin
Additive: 1% wax emulsion (bas on OD weight of flakes)
Mat moisture content: 9-10%
Mat construction: three-layer, with the small flakes in the core and large flakes equally divided between face layers
Press temperature: 340°F
Press cycle: 1 min to thickness, then pressure necessary to maintain position
Total press time: 8 min
Postcure: Immediately after pr ing, panels were hotstacked overnight in an insulated box

Testing the Panels

After manufacture, the unsanded pa were cut into test specimens, conditio at 50 percent relative humidity (RH), tested according to ASTM D 1037-72a (1 Four specimens were tested for bending 50 percent RH and two after accelerate aging (AA). Bending strength (MOR) an stiffness (MOE) of aged specimens were calculated based on specimen dimension before aging.

Two internal bond (IB) specimens were cut from each tested bending spec men. Dimensional stability tests were

performed on specimens subjected to ovendry vacuum-pressure soak (OD-VPS) (2), relative humidity exposure between 30 and 90 percent RH at 80° F., and 24-hour water soak (WS).

Results and Discussion

Part I. Screen Analysis and Resin Coverage

The percentage of fines varied significantly by flaker (Figs. 1-5).[3] The ring flaker produced from 21.4 to 25.6 percent fines, depending on the species (table 1). Drum, lathe, and disk flakers yielded 7.7, 3.5, and 2.2 percent fines. The most fines the lathe and drum flakers produced was in cutting oak (6.9 and 12.4 percent). The disk flaker made most fines when cutting lodgepole pine and hickory (3.2 and 3.5 percent).

From the material that was to be used in panel fabrication, 50 flakes per screen size were measured for length, width, and thickness.[4] Disk-cut flakes had the smallest surface area per pound of flakes followed by the lathe-cut flakes (Table 2). Ring-cut flakes had the largest surface area per pound except for loblolly pine for which drum flakes had the largest. Since constant amounts of resin were applied per thousand square feet of flake surface area were inversely correlated with surface area per pound of flakes.

A flake length to thickness ratio of 112.5 was anticipated, i.e., 2.25-inch target flake length/0.020-inch target flake thickness. Although very few flakes remained on the 2-inch screen (Table 1), average length exceeded 2 inches for flakes remaining on screens as small as 1/2 inch. In general, flake thickness did not change with screen sizes above 1/2 inch, and the thinnest flakes were on the 1/16-inch screen. Except with the disk flaker, the anticipated length to thickness ratio of flakes retained on 1/2-inch and larger screens was achieved (Fig. 6). The low disk-flaker ratio occurred because flake thickness exceeded target thickness; the other flakers yielded slightly less than target thickness. Dimension ratio varied more for core flakes than face flakes.

Part II. Flaking Alternatives for Low-Density Species

Bending Strength (MOR)

The interactions of resin content with flaker type, species with flaker type, and species with CR were significantly related to MOR for sweetgum, loblolly pine, and lodgepole pine. When the data were

---

[3]Statistical data for the study are available from the authors.

[4]Tables containing these data are available from the authors.

---

analyzed by flaker and CR, the only combination having a significant interaction was drum-flake panels with low CR.

Increasing resin content from 5 to 8 percent raised MOR an average of 15 percent at the lower compression ratio and 10 percent at the higher compression ratio. The MOR of the ring-flake panels increased 20 percent with resin content; the MOR of disk-flake panels increased least (3 percent). The MOR increased and 12 and 14 percent in lathe- and drum-flake panels.

Expressing panel densities as CR, averaging the resin contents, and assuming a linear relationship with MOR over the CR data range allowed analysis of the species with flaker interaction--without the confounding effect of fabrication CR variability (Table 3, Figs. 7 and 8). Lodgepole pine panels made from lathe flakes had higher initial condition (50 percent RH) bending strength than lodgepole pine panels made of the other flakes. Although the ring- and disk-flake lodgepole pine panels had lower initial MOR values, both had higher AA values than the lathe-flake panels at high CR. In both initial and AA tests, the drum-flake panels had lower MOR than the lathe-flake panels.

With one exception (loblolly pine panels at low CR after AA), loblolly pine and sweetgum panels of drum-cut flakes had the lowest MOR for the initial condition and after AA. Under initial conditions, loblolly panels of disk flakes at low CR and of lathe flakes at high CR had high MOR's. The values for ring panels were intermediate at low and high CR. After AA, the disk panels maintained the high MOR for loblolly panels at low CR, but the ring panels had the highest MOR at high CR. For sweetgum, the disk was high at the high CR and ring panels at low CR.

The ring-flake panels under initial conditions had MOR's proportional to the densities of the species (Table 3). Panels made of lathe-cut and drum-cut flakes showed little variation among species in initial MOR. Panels of drum-cut flakes had the lowest MOR for all species and the slope of the MOR/CR relationship increased with species density.

Modulus of Elasticity (MOE)

An increase in resin content did not increase average MOE as much as it did average MOR; the increase in MOE was 7.4 percent and the increase in MOR was 12 percent. Increasing resin content from 5 to 8 percent increased MOE of ring-flake panels 13.5 percent. Drum-flake panels had an 8.7 percent increase; disk-flake panels, a 5.3 percent increase; and lathe-flake panels, a 2.7 increase. The increase in

Table 1.--PERCENT OF MATERIAL RETAINED ON EACH SCREEN SIZE.

Species and Flaker	2	1	1/2	1/4	1/8	1/16	Fines[1]
					%		
Lodgepole pine							
Disk	4.1	48.7	25.9	11.6	3.2	3.3	3.2
Drum	1.7	45.2	20.8	13.1	6.3	5.7	7.2
Ring	0.	.4	5.6	31.8	20.6	20.1	21.4
Lathe	.3	56.8	27.3	10.2	1.5	1.4	2.8
Loblolly pine							
Disk	5.8	61.2	23.8	5.7	1.1	1.1	1.3
Drum	0	24.6	33.5	19.6	8.3	6.9	7.1
Ring	0	.2	2.4	25.4	24.0	22.4	25.6
Lathe	0	17.8	44.5	25.9	4.5	3.2	4.1
Sweetgum							
Disk	4.3	60.3	23.8	7.6	1.4	1.1	1.5
Drum	0	39.4	31.4	13.8	5.9	4.8	4.7
Drum, +1A[2]	0	1.8	32.2	34.9	14.1	9.3	7.7
Ring	0	.1	3.8	31.9	19.4	20.1	24.7
Lathe	0	64.3	27.2	5.5	1.0	.7	1.3
Red oak							
Disk	1.2	39.0	35.5	19.0	2.4	1.2	1.7
Drum	0	4.5	19.5	36.7	14.7	12.2	12.4
Ring	0	0	.5	22.0	25.8	26.2	25.5
Lathe	0	4.6	28.0	44.1	9.9	6.5	6.9
Hickory							
Disk	.9	46.9	27.2	13.5	4.8	3.3	3.5
Disk, + 1A[2]	0	4.2	42.1	33.1	11.0	4.8	4.8
Drum	0	25.9	32.3	20.7	7.9	6.3	6.9
Drum, +1/2A[3]	0	.7	10.3	49.6	17.7	11.9	9.8
Ring	0	0	1.7	25.7	27.8	23.7	21.1
Lathe	1.0	33.8	34.1	21.1	5.3	2.4	2.3

[1] Material that passed through the 1/16-in screen.
[2] Flakes on the 1 and larger screens were passed through the drum chipper, added to the other screens, and rescreened to yield the tabulated percentages for panel fabrication.
[3] Flakes on the 1/2 and larger screens were passed through the drum chipper, added to the other screens, and rescreened to yield the tabulated percentages for panel fabrication.

Table 2.--FLAKE SURFACE AREA AND RESIN SOLIDS PER UNIT OF FLAKE AREA.

Species and Flaker	Flake Surface Area — Per Pound of Flakes						Per Panel[1]		Resin Solid/MSF of Flake Surface Area		
	2	1	1/2	+1/4"	1/8	1/16	Face	Core	5% Resin Face	Core	8% Res Face
				Ft²						Lb	
SWEET GUM											
Disk	30.08	35.27	41.05	45.61	62.80	74.32	132.97	156.07	1.418	1.208	2.269
Drum	-	52.32	53.91	58.32	80.15	91.30	207.32	269.50	0.909	0.699	1.455
Lathe	-	47.25	51.30	55.05	58.78	86.42	178.13	192.90	1.058	0.977	1.693
Ring	-	48.69	58.39	72.99	80.11	86.21	272.66	313.71	0.691	0.601	1.106
LOBLOLLY PINE											
Disk	35.49	34.58	34.90	40.41	50.32	58.11	125.53	132.61	1.446	1.369	2.314
Drum	-	81.35	82.68	83.20	93.62	103.78	297.57	319.48	0.610	0.568	0.976
Lathe	-	49.67	51.96	55.46	60.76	82.45	185.71	206.85	0.977	0.877	1.564
Ring	-	62.74	70.29	71.30	80.85	90.93	266.88	315.44	0.680	0.575	1.088
LODGEPOLE PINE											
Disk	45.46	51.51	50.49	75.64	96.33	102.83	147.83	184.73	0.971	0.777	1.553
Drum	68.67	73.80	75.25	94.26	106.79	120.35	211.81	259.98	0.678	0.552	1.084
Lathe	53.51	73.46	83.69	88.19	98.29	127.69	210.83	243.97	0.681	0.588	1.089
Ring	-	82.56	87.34	100.41	107.65	128.72	282.10	338.78	0.509	0.424	0.814
RED OAK											
Disk	19.92	29.34	31.38	32.36	42.51	59.85	138.43	153.70	1.683	1.516	2.693
Drum	-	46.14	46.11	52.55	73.62	78.04	228.26	310.46	1.021	0.751	1.633
Lathe	-	37.86	46.88	57.61	63.39	83.86	229.26	291.17	1.016	0.800	1.626
Ring	-	-	51.58	75.04	79.10	84.48	355.94	386.15	0.655	0.603	1.047
HICKORY											
Disk	-	22.30	22.01	25.94	31.87	52.21	122.92	166.62	2.269	1.674	3.630
Drum	-	35.60	35.44	41.98	43.61	74.28	221.85	287.15	1.257	0.971	2.011
Lathe	26.20	30.50	33.39	34.98	38.75	75.70	174.96	205.24	1.594	1.359	2.550
Ring	-	-	63.80	65.59	65.70	73.97	365.61	394.13	0.763	0.708	1.221

[1] The panels were 1/2 by 24 by 28 in. for 1.25 compression ratio.

MOE of ring- and drum-flake panels caused by adding resin were significant for all test condition-CR combinations, but the MOE of disk panels significantly increased only at low CR under initial conditions. Increasing resin content did not affect the MOE of lathe-flake panels.

As with MOR, assuming a linear relationship between MOE and CR, and averaging the two resin contents, allowed analyses of flaker-species interactions without the confounding effect of fabrication CR variability (Table 3, Figs. 9 and 10). At initial condition, the lathe produced the stiffest lodgepole and loblolly pine panels at the high CR. After AA, the only species for which lathe-flake panels were stiffest was lodgepole pine at the low CR. Disk- and ring-flake panels had highest MOE for all other species, test conditions, and CR's. The drum-flake panels generally had the lowest or next to the lowest MOE for all species and test conditions. Lathe-flake panels showed least variation in MOE among species and the ring-flake panels were particularly correlated with species density.

Internal Bond (IB)

Interactions of resin content with species and flaker, and interactions of flaker and compression ratio were significant for initial and AA tests. One explanation for the complicated interactions may be differences in resin coverage among panel types. For example, at initial condition, boards made from drum flakes had a substantial species-CR interaction in which the IB's of sweetgum panels were correlated with CR, but the IB's of loblolly and lodgepole pine panels were not (Fig. 11). Large sweetgum flakes were passed through a drum chipper to reduce their width (see footnote 2 of Table 1), but large flakes of lodgepole and loblolly pines were not. Putting the sweetgum flakes through the drum chipper may have allowed them to receive more uniform resin distribution. Surface area per pound of material and material bulk density also may have affected resin distribution.

Whether one relates flakers to individual species or to the average of all three species, ring-flake panels had highest IB followed by disk-, lathe-, and drum-flake panels (Figs. 11 and 12). The 3 percent resin content increase generally increased IB of panels under initial and AA conditions; the average increase was 31 percent for initial IB (68 to 89 psi) and 11 percent after AA. The significant interaction of resin content with species meant that the higher density species, loblolly pine and sweetgum, had smaller increases in initial IB with increased resin, i.e., lodgepole pine had a 44 percent increase, loblolly pine 34 percent, and sweetgum 17 percent.

Lodgepole pine panels made with ring, disk, or lathe flakes had lowest IB of the three species (Table 3). Lodgepole and loblolly pine panels of drum flakes had about the same IB's. Loblolly pine panels of ring or lathe flakes generally had a higher IB than sweetgum for equivalent CR's. Sweetgum panels had highest IB's among panels made of disk-cut flakes. After AA, the IB's were drastically reduced. However, the species-flaker relationships generally remained the same as the initial relationship.

Linear Expansion (LE)

Linear expansion data were stratified by each major variable for the three environmental treatments (Table 4). For all experimental conditions, the OD-VPS treatment caused most LE and the WS least LE. With few exceptions, if a change in LE occurred as the CR increased, LE increased for 30 to 90 percent RH and decreased for WS and OD-VPS (Fig. 13).

Panels made of lathe flakes had less LE than any of the other panels for all species under the OD-VPS cycle. For 30 to 90 percent RH, drum flake panels had the least LE for lodgepole pine, lathe-flake panels for loblolly pine, and ring- and lathe-flake panels were about the same for sweetgum (Table 4). In the WS cycle, lathe-flake and disk-flake panels had the least LE at low CR for lodgepole and loblolly pines and lathe-flake panels had least LE at both CR's for sweetgum. Lodgepole and loblolly pine panels of disk flakes had lowest LE at high CR in the WS cycle.

Lodgepole pine generally had the least LE for the OD-VPS condition for all flakers (Fig. 13). In general, LE did not increase greatly with increasing CR; exceptions were lathe-flake panels of loblolly given the OD-VPS cycle and loblolly ring- and disk-flake panels given 30 to 90 percent RH cycle.

Thickness Swell (TS)

In general, 30 to 90 percent RH caused the least TS; WS caused slightly more; and the OD-VPS caused about twice as much TS as the 30 to 90 percent RH cycle. Increasing resin content had least effect under test conditions that caused the least TS; adding to the resin content decreased TS by 2.7, 4.0, and 7.6 percent for 30 to 90 percent RH, WS, and OD-VPS cycles.

The drum-flake panels had no combination of species and test cycle that produced a low TS (Table 4). Disk-flake panels made with sweetgum flakes had a TS for the 30 to 90 percent RH cycle close to the lathe's. Especially at the high CR, loblolly and lodgepole pine disk-flake panels had little TS for the WS. Ring-flake panels had least TS for the OD-VPS cycle when made of lodgepole pine at the high CR. In all other cases, the lathe panels had least TS.

51

Table 3.—STRENGTH PROPERTIES OF PANELS FROM FLAKES OF THREE SPECIES, CUT ON FOUR TYPES OF FLAKERS.

Flaker	Species[1]	Panel Density at 50% RH (Pcf)	Bending Strength (Psi) Initial[2]	Bending Strength (Psi) AA[2]	Modulus of Elasticity (Thousand Psi) Initial	Modulus of Elasticity (Thousand Psi) AA	Internal Bond (Psi) Initial	Internal Bond (Psi) AA
Ring	LP	28.9 / 34.3	3,141 / 4,878	2,837 / 4,542	432.8 / 589.8	390.7 / 591.8	68.6 / 101.7	35.3 / 60.1
	LL	37.4 / 42.6	4,200 / 5,397	3,569 / 4,879	555.0 / 691.1	483.8 / 638.9	96.6 / 133.7	44.8 / 69.0
	SG	37.6 / 45.5	3,936 / 5,714	3,151 / 4,913	543.1 / 753.0	449.9 / 680.7	82.7 / 137.3	15.4 / 18.9
Disk	LP	30.5 / 35.9	3,358 / 4,892	3,013 / 4,987	514.4 / 660.6	462.0 / 683.2	70.6 / 97.5	33.3 / 46.8
	LL	38.1 / 45.1	4,609 / 5,806	3,825 / 5,112	603.2 / 746.9	527.7 / 671.0	82.3 / 103.9	33.3 / 55.9
	SG	40.9 / 45.7	4,803 / 6,773	4,133 / 5,980	649.2 / 842.8	568.2 / 810.8	92.2 / 113.2	33.7 / 40.4
Lathe	LP	32.6 / 38.4	4,738 / 6,490	4,189 / 4,941	615.2 / 802.2	555.0 / 726.4	47.8 / 56.7	10.9 / 7.9
	LL	38.1 / 42.5	4,026 / 5,415	2,973 / 4,452	568.5 / 725.1	417.7 / 617.4	59.7 / 87.8	24.9 / 30.4
	SG	40.4 / 47.7	4,231 / 6,356	3,419 / 5,328	575.6 / 758.6	416.1 / 622.7	60.0 / 77.0	17.6 / 17.9
Drum	LP	31.6 / 39.1	3,631 / 4,621	2,967 / 3,284	537.2 / 699.8	425.0 / 503.4	43.2 / 44.8	11.9 / 8.9
	LL	40.0 / 46.7	4,068 / 5,574	3,532 / 4,978	591.1 / 793.8	478.2 / 676.4	42.3 / 47.3	21.3 / 16.1
	SG	40.0 / 47.5	3,573 / 5,601	3,048 / 4,726	498.1 / 709.9	385.9 / 588.7	52.3 / 91.3	21.4 / 26.8

[1] LP = lodgepole pine, LL = loblolly pine, SG = sweetgum.
[2] Initial = 50% RH, AA = After accelerated aging.

Table 4.—DIMENSIONAL STABILITY PROPERTIES OF PANELS MADE FROM FLAKES OF THREE SPECIES, CUT ON FOUR TYPES OF FLAKERS.

Flaker	Species[1]	CR[2]	Linear Expansion (%) 30-90% RH	Linear Expansion (%) 24-HR WS[3]	Linear Expansion (%) OD-VPS	Thickness Swell (%) 30-90% RH	Thickness Swell (%) 24-HR WS	Thickness Swell (%) OD-VPS
Ring	LP	1.22 / 1.45	.15 / .16	.11 / .08	.26 / .23	14.2 / 15.4	18.5 / 15.9	23.6 / 22.3
	LL	1.26 / 1.43	.12 / .14	.11 / .09	.27 / .26	14.4 / 14.7	18.9 / 19.3	25.9 / 30.1
	SG	1.21 / 1.47	.15 / .14	.10 / .03	.28 / .24	16.1 / 16.8	22.4 / 19.9	31.2 / 35.5
Disk	LP	1.29 / 1.51	.15 / .15	.07 / .00	.23 / .23	15.1 / 14.4	18.6 / 13.2	24.4 / 30.7
	LL	1.28 / 1.51	.13 / .15	.07 / .03	.23 / .23	13.4 / 13.9	17.6 / 15.7	22.2 / 31.5
	SG	1.32 / 1.47	.20 / .20	.06 / -.01	.27 / .22	13.2 / 13.7	13.9 / 12.5	27.4 / 34.1
Lathe	LP	1.38 / 1.62	.11 / .12	.07 / .06	.18 / .17	11.9 / 12.7	17.9 / 22.9	20.6 / 29.3
	LL	1.28 / 1.43	.11 / .12	.07 / .07	.17 / .21	12.2 / 13.9	20.8 / 21.2	23.3 / 28.6
	SG	1.30 / 1.54	.15 / .14	.01 / -.07	.21 / .15	13.6 / 14.6	9.9 / 9.8	25.5 / 30.9
Drum	LP	1.33 / 1.65	.07 / .09	.08 / .05	.19 / .18	15.8 / 15.2	22.5 / 23.8	28.1 / 36.5
	LL	1.34 / 1.57	.14 / .16	.11 / .13	.23 / .25	15.6 / 17.3	26.7 / 30.0	27.0 / 33.3
	SG	1.30 / 1.52	.18 / .20	.14 / .06	.33 / .31	14.9 / 15.3	17.1 / 12.0	29.7 / 32.2

[1] LP = lodgepole pine, LL = loblolly pine, SG = sweetgum.
[2] CR = compression ratio.
[3] 24-HR WS = 24-hour water soak. ... soak

Bending Strength (MOR)

At the target density of 52.6 pcf, type of flaker, resin content, and species affected bending strength. The 3 percent addition of resin resulted in an 18 percent strength increase for initial condition (Table 5). Panels with high resin content retained 73 percent of their initial bending strength after AA; panels with low resin content retained only 65 percent of their initial bending strength after AA.

Since the bending strengths of panels of the two species were significantly different, the panels of the two species were fabricated at different CR's; thus, an analysis of the effect of CR on bending strength for different flaker-species cominations was possible (Table 6, Fig. 14). Besides the 52.6 pcf density, red oak panels were targeted to be made at 47.6 pcf and hickory panels at 57.6 pcf. Although the fabrication densities differed from the 52.6 pcf by only 5 pcf, a linear relationship over the plotted CR range was assumed.

The lathe-flake panels were usually strongest for the two species and both test conditions (Table 6). The ring-flake panels usually were next strongest. Slopes of disk- and ring-flake panels were similar (Fig. 14). Drum-flake panels had steep slopes and were usually weakest at low CR, but their strength approached that of lathe-flake panels at high CR.

Hickory panels were stronger than red oak panels at equivalent CR's and had steeper slopes. At equivalent panel densities, e.g., 52.6 pcf, red oak panels were usually slightly stronger than hickory panels.

Modulus of Elasticity (MOE)

The average MOE's for panels of the four flakers fabricated at 52.6 pcf ranged from 748,000 to 848,000 psi at initial test condition, and from 515,000 to 628,000 psi after AA (Table 5). The MOE's of drum-flake panels were lowest among flakers for initial and AA conditions; lathe panels generally had the highest MOE for the two species and both test conditions (Fig. 15).

Resin content significantly affected MOE, but panels with 8 percent resin content also were denser than those with 5 percent resin content (Table 5). Boards with high resin content had a specific modulus (MOE/density) that was 8 percent higher than panels with low resin content; moreover, the panels with high resin content retained a higher proportion of their strength after AA than those with low resin content.

Resin content and species were significantly related to MOE of lathe-flake panels under both test conditions. Initial strength of ring-flake and disk-flake panels varied with species; strength of these panels after AA varied only with resin content. Using average resin content, species and species-flaker effects were obtained for a CR range (Fig. 15). At an equivalent CR, hickory panels were stiffer than red oak panels. Also, the average slope of the four flakers for the hickory panels was steeper for both test conditions than the average slope of the red oak panels. Disk-flake panels of red oak, however, had a steeper slope than hickory panels at initial condition. After AA, ring- and lathe-flake panels of red oak had steeper slopes than the corresponding hickory panels.

Internal Bond (IB)

At 52.6 pcf, the ring-flake panels had highest IB under all circumstances except for panels fabricated at 5 percent resin content and exposed to accelerated aging (Fig. 16). At the low resin content after AA the range of the IB for the four flakers was only 7 psi. The IB's of the disk, lathe, and drum panels were similar, except for the lathe-flake panel at 8 percent resin content under initial conditions.

Although red oak panels had a higher IB than hickory panels at equivalent densities, IB of hickory panels generally exceeded that of red oak panels at equivalent CR's (Table 6, Fig. 17). Panels made of ring flakes had highest initial IB's for both species over the range of CR's.

Linear Expansion (LE)

In all cases, the OD-VPS values for LE were highest, followed by the 30 to 90 percent RH values, and then the 24-hour WS (Tables 5 and 7). For all three tests, the only factor that was significant by itself was flaker type. In most panels, additional resin did not decrease LE. Red oak and hickory fabricated at approximately 52.6 pcf had equivalent LE's, but generally, over the CR range, red oak had a slightly lower LE than hickory (Fig. 18).

The drum-flake panels had an LE that was either uniform or that decreased with increasing CR for 30 to 90 percent RH and OD-VPS (Fig. 18). A decrease also occurred for disk-flake panels of red oak under the 30 to 90 percent RH test. At high CR, the drum-flake panels had the lowest LE. The ring- and lathe-flake panels had similar LE's that were usually lower than those of the drum- or disk-flake panels.

Thickness Swell (TS)

Unlike with linear expansion, resin content, species, and flaker significantly affected TS for the three test conditions. Interactions affected TS for the 30 to 90

Table 5.--AVERAGE STRENGTH AND DIMENSIONAL STABILITY PROPERTIES FOR RED OAK AND HICKORY PANELS, FABRICATED AT A TARGET DENSITY OF 52.6 PCF WITH FLAKES CUT ON FOUR TYPES OF FLAKERS.

	Panel Density at 50% RH	MOR INIT[1]	MOR AA[1]	MOE INIT	MOE AA	IB INIT	IB AA	Linear Expansion 30-90% RH	24-HR WS[1]	OD-VPS[1]	Thickness Swell 30-90% RH	24-HR WS	OD-VP
	Pcf	--- Psi ---		Thousand Psi		----Psi----				%			
Overall	52.4	6641	4586	793	564	167	34	.20	.03	.30	12.9	10.5	28.9
Flaker													
Ring	51.3	6601	4537	756	561	219	44	.18	.03	.32	13.5	14.4	33.0
Disk	52.7	6277	4379	820	552	129	30	.23	.02	.34	11.7	9.0	28.4
Lathe	53.3	7604	5263	848	628	167	29	.21	-.01	.26	9.9	8.4	24.
Drum	52.2	6084	4164	748	515	154	33	.17	.06	.29	16.5	10.5	30.
Species [2]													
RO	52.2	7009	4789	864	605	175	35	.19	.03	.30	12.0	8.9	28.
HI	52.5	6274	4383	722	523	160	33	.20	.03	.31	13.8	12.2	29.
Resin %													
5	51.7	6091	3944	757	514	138	22	.20	.02	.31	14.3	12.6	33.
8	53.0	7192	5228	829	614	196	46	.20	.03	.30	11.4	8.5	23.

[1] Initial = 50% RH test condition. AA = after acclerated aging. 24-HR WS = 24-hour water soak. OD-VPS = ovendry vacuum pressure soak

[2] RO = Red oak, HI = Hickory

Table 6.--STRENGTH PROPERTIES OF RED OAK AND HICKORY PANELS FROM FLAKES CUT ON FO TYPES OF FLAKERS.

Flaker	Species[1]	Panel Density at 50% RH	Bending Strength Initial[2]	AA[2]	Modulus of Elasticity Initial	AA	Internal Bond Initial	AA
		---Pcf---	----Psi----		---Thousand Psi---		----Psi----	
Ring	RO	46.4	5393	3758	697.7	485.9	168	37
		50.9	6590	4462	799.0	578.6	218	40
	HI	51.7	6634	4613	713.6	543.1	221	47
		55.0	7347	5103	821.1	589.0	232	39
Disk	RO	48.4	5416	3876	764.6	494.0	75	28
		52.9	6715	4559	899.7	574.5	108	23
	HI	52.6	5834	4198	740.5	528.6	150	37
		56.7	6756	4821	792.6	600.3	160	36
Lathe	RO	48.6	6625	4307	800.9	572.9	174	23
		53.3	8070	5470	902.7	677.0	205	30
	HI	53.2	7138	5057	792.4	579.7	128	27
		56.0	8206	5527	863.4	609.2	177	30
Drum	RO	49.4	5409	3906	744.6	538.0	122	20
		51.7	6662	4664	854.2	589.9	168	45
	HI	52.7	5507	3664	641.4	441.0	140	22
		55.1	6849	4548	772.5	539.5	177	27

[1] RO = Red oak, HI = Hickory.
[2] Initial = 50% RH, AA = After accelerated aging.

54

Table 7.--DIMENSIONAL STABILITY PROPERTIES OF RED OAK AND HICKORY PANELS MADE FROM FLAKES FROM FOUR TYPES OF FLAKERS.

Flaker	Species[1]	CR[2]	Linear Expansion			Thickness Swell		
			30-90% RH	24-HR WS	OD-VPS[3]	30-90% RH	24-HR WS	OD-VPS
			--- % ---					
Ring	RO	1.21	.16	.08	.30	14.4	15.7	32.1
		1.33	.18	.00	.31	14.1	11.7	34.1
	HI	1.13	.19	.08	.33	12.9	17.1	31.9
		1.20	.22	.06	.42	10.4	19.3	34.9
Disk	RO	1.26	.22	.02	.28	12.1	10.2	27.4
		1.38	.19	.01	.31	10.8	8.0	29.0
	HI	1.15	.27	.02	.38	12.6	9.8	27.9
		1.24	.31	.01	.39	11.5	7.8	30.1
Lathe	RO	1.27	.17	.04	.24	11.7	9.1	23.2
		1.39	.22	.02	.28	8.8	7.5	24.5
	HI	1.16	.21	-.04	.24	11.1	9.2	23.9
		1.22	.24	.00	.30	12.2	8.2	24.7
Drum	RO	1.29	.19	.09	.30	15.5	9.6	28.1
		1.35	.20	.06	.27	14.5	8.6	25.3
	HI	1.15	.20	.05	.31	17.8	10.2	37.9
		1.20	.14	.06	.31	18.5	12.4	35.0

[1] RO = Red Oak, HI = Hickory.

[2] CR = Compression ratio

[3] 24 HR WS = 24-hour water soak; OD-VPS = ovendry-vacuum pressure soak.

Table 8.--STRENGTH AND DIMENSIONAL STABILITY PROPERTIES OF PANELS FROM FLAKES OF FIVE SPECIES, CUT ON FOUR TYPES OF FLAKERS.

	Density at 50% RH	MOR		MOE		IB		Linear Expansion			Thickness Swell		
		INIT[1]	AA[1]	INIT[1]	AA[1]	INIT	AA	30-90% RH	24-HR WS[1]	OD-VPS[1]	30-90% RH	24 HR WS	OD-VPS
	Pcf	--- Psi ---		Thousand Psi		--- Psi ---		--- % ---					
Overall	42.6	5016	3825	647	499	105	27	0.17	0.07	0.27	13.9	15.8	27.4
Flaker													
Ring	41.1	4803	3684	610	480	132	34	.16	.09	.31	14.4	19.0	29.5
Disk	42.9	4988	3934	665	530	96	33	.20	.05	.28	13.0	13.6	26.3
Lathe	43.1	5565	4083	685	514	104	21	.15	.04	.22	12.1	13.2	23.5
Drum	43.3	4706	3600	629	473	87	20	.16	.09	.27	15.9	17.2	30.2
Species [2]													
LP	30.9	3717	3252	525	458	58	23	.12	.08	.21	14.3	19.4	24.2
LL	39.4	4226	3475	579	477	70	31	.12	.09	.22	13.9	21.0	24.8
SG	39.8	4136	3438	567	455	72	22	.17	.08	.27	14.2	15.9	28.3
RO	48.2	5711	3962	752	523	135	27	.18	.06	.28	13.4	11.1	27.8
HI	55.7	7290	4999	812	585	189	33	.24	.03	.35	13.5	11.4	31.9
Resin %													
5	42.2	4643	3415	623	463	86	16	.16	.06	.26	15.4	18.0	31.6
8	43.0	5389	4235	671	536	123	39	.17	.08	.28	12.3	13.5	23.2

[1] INIT = 50% RH test condition.
AA = after accelerated aging.
24-HR WS = 24=hour water soak.
OD-VPS = ovendry vacuum-pressure soak.

[2] LP = lodgepole pine, LL = loblolly pine,
SG= sweetgum, RO = red oak, HI = hickory.

percent RH and OD-VPS. In all cases, the OD-VPS cycle caused the most TS.

Lathe- and disk-flake panels had least TS for all three tests (Table 5). Except for the 30 to 90 percent RH cycle, ring-flake panels had greatest TS. The TS of ring-flake panels from the WS exceeded that from the 30 to 90 percent RH cycle.

Red oak panels fabricated at a density of 52.6 pcf had less TS than hickory panels (Table 5). Under the OD-VPS evaluation, red oak panels yielded lower TS and a lower rate of TS change per CR change than hickory panels of all flake types (Table 7), Fig. 18). With both species, TS of lathe-, disk-, and ring-flake panels increased with CR for the OD-VPS cycle; TS of drum-flake panels decreased.

The 30 to 90 percent environment caused a slight decrease in TS with increasing CR for all red oak panels and for disk- and ring-flake hickory panels. For the lathe- and drum-flake panels of hickory, low CR yielded low TS.

Except for disk-flake panels subjected to 30 to 90 percent RH and ring-flake panels subjected to WS, resin content was a significant factor for the individual flakers. Increasing resin decreased TS an average of 2.9, 4.1, and 10 percent for 30 to 90 percent RH, WS, and OD-VPS. The largest decrease occurred for ring-flake panels followed by drum-, lathe-, and disk-flake panels (Fig. 19). Lathe-flake panels had the lowest TS for all test conditions at equivalent resin contents.

Part IV. Selecting a Flaker: Comparing the Five Species

Based on observed means of panels fabricated at 1.25 CR, this section presents major trends and effects to allow an assessment of the flakers.

Bending Strength (MOR)

Panels of lathe flakes had the highest average strength followed by disk-, ring-, and drum-flake panels for initial (50 percent RH) and accelerated-aging test conditions (Table 8). Accelerated aging lowers bending strength of panels from all the flakers. Lathe-flake panels were strongest for the species with the lowest specific gravity (lodgepole pine) and the two species with the highest specific gravities (Table 9). Loblolly pine and sweetgum panels made from disk flakes were strongest. Although the lathe- and disk-flake panels were strongest overall, each also had a panel of one species that was weakest, i.e., hickory for the disk and loblolly pine for the lathe.

Increasing resin content from percent raised MOR an average of 16 cent; after accelerated aging, MOR percent higher for the 8 percent re content than for the 5 percent. By creasing resin content, bending str for lathe- and disk-flake panels in 14.3 and 10.8 percent, while the r and drum-flake panels had a 19.0 pe increase. Except with lathe-flake the greatest strength increase caus increasing resin content occurred w hickory; lodgepole pine had the larg strength increase for the lathe-fla panels.

Modulus of Elasticity (MOE)

The MOE trends were similar to of bending strength. An increase in content increased MOE of all except panels. At the higher resin content the ring- and drum-flake panels yiel 10.4 percent increase in MOE, but th had only an 8.0 percent increase. T average MOE increase of the lathe-fl panels was smallest (2.3 percent), b lodgepole pine panels fabricated wit flakes had the greatest (18.2 percen increase with increased resin conten

Panels of different species fabr at the target compression ratio (CR) 1.25 did not produce the same MOE. then red oak, had the highest averag and the highest MOE for each flaker Table 9). The lathe produced the st panel for high- and low-density spec the disk for the two intermediate sp (sweetgum and loblolly pine). The d indicated that as species density in the CR can decrease to obtain equiva properties. For instance, hickory, cated at the lowest CR (1.21), was su Hickory and red oak could have been cated at even lower CR's to obtain st ness values equal to those of the oth species.

Internal Bond (IB)

The ring-flake panels had the hi IB for the 50 percent RH and after ac ated aging (Table 8). At 50 percent the ring-flake panels' IB was 28 psi than the lathe-flake panels" IB, whic next highest. The IB's of the ring- disk-flake panels after aging differe only 1 psi and were greater than the of the lathe-flake and drum-flake pan

As species density increased, in IB increased from 58 psi to 189 psi (Table 8). At 50 percent RH, the rin flake panels' IB was 28 psi higher th lathe-flake panels' IB, which was nex highest. The IB's of the ring- and d flake panels after aging differed by 1 psi and were greater than the IB's lathe-flake and drum-flake panels.

Table 9.--STRENGTH PROPERTIES OF PANELS FROM FLAKES OF FIVE SPECIES, CUT ON FOUR TYPES OF FLAKERS.

Flaker Species[1]		Bending Strength		Modulus of Elasticity		Internal Bond	
		Initial[2]	AA[2]	Initial[2]	AA[2]	Initial[2]	AA[2]
		------Psi------		---Thousand Psi---		------Psi------	
Ring	LP	3,141	2,837	432.8	390.7	68.6	35.3
	LL	4,200	3,569	555.0	483.8	96.6	44.8
	SG	3,936	3,151	543.1	449.9	82.7	15.4
	RO	5,393	3,758	697.7	485.9	168.0	37.3
	HI	7,347	5,103	821.1	589.0	244.2	39.2
Disk	LP	3,358	3,013	514.4	462.0	70.6	33.3
	LL	4,609	3,825	603.2	527.7	82.3	33.3
	SG	4,803	4,133	649.2	568.2	92.2	33.7
	RO	5,416	3,876	764.6	493.9	75.2	27.8
	HI	6,756	4,821	792.6	600.3	159.4	36.2
Lathe	LP	4,738	4,189	615.2	555.0	47.8	10.9
	LL	4,026	2,973	568.5	417.7	59.7	24.9
	SG	4,231	3,419	575.6	416.1	60.0	17.6
	RO	6,625	4,307	800.9	572.9	174.1	22.8
	HI	8,206	5,526	863.4	609.2	176.9	30.1
Drum	LP	3,631	2,967	537.2	425.0	43.2	11.9
	LL	4,068	3,532	591.1	478.2	42.3	21.3
	SG	3,573	3,048	498.1	385.9	52.3	21.4
	RO	5,409	3,906	744.6	538.0	122.1	20.4
	HI	6,849	4,548	772.4	539.5	176.6	26.8

[1] LP = lodgepole pine, LL = loblolly pine, SG = sweetgum, RO = red oak, HI = hickory.

[2] Initial = 50% RH; AA = after accelerated aging.

Table 10.--DIMENSIONAL STABILITY PROPERTIES OF PANELS FROM FLAKES OF FIVE SPECIES, CUT ON FOUR TYPES OF FLAKERS.

Flaker Species[1]		Linear Expansion			Thickness Swell		
		30-90% RH	24-HR WS[2]	OD-VPS[2]	30-90% RH	24-HR WS	OD-VPS
		%					
Ring	LP	0.15	0.11	0.26	14.1	18.6	23.6
	LL	.12	.11	.27	14.4	18.9	25.9
	SG	.15	.10	.28	16.1	22.4	31.2
	RO	.16	.07	.30	14.3	15.7	32.0
	HI	.22	.06	.42	12.8	19.3	34.9
Disk	LP	.15	.07	.23	15.1	18.6	24.4
	LL	.13	.07	.23	13.4	17.6	22.2
	SG	.20	.06	.22	13.2	13.9	27.4
	RO	.21	.02	.28	12.1	10.2	27.4
	HI	.31	.02	.39	11.4	7.8	30.1
Lathe	LP	.11	.07	.18	11.9	17.9	20.6
	LL	.11	.07	.17	12.2	20.8	23.3
	SG	.15	.01	.21	12.6	9.9	25.6
	RO	.17	.04	.24	11.7	9.1	23.7
	HI	.23	.00	.30	12.2	8.2	24.7
Drum	LP	.07	.08	.19	15.8	22.5	28.1
	LL	.14	.11	.23	15.6	26.7	27.6
	SG	.18	.14	.33	14.9	17.1	29.1
	RO	.19	.09	.29	15.5	9.6	28.1
	HI	.20	.04	.31	17.7	10.2	37.9

[1] LP = lodgepole pine, LL = loblolly pine, SG = sweetgum, RO = red oak, HI = hickory.

[2] 24-HR WS = 24-hour water soak. OD-VPS = ovendry vacuum-pressure soak.

Linear Expansion (LE)

Except for drum-flake panels of lodgepole pine, the 24-hour water soak (WS) condition produced less LE than 30 to percent RH. The OD-VPS caused more LE than either of the other test conditions for all experimental factors (Table 8). Increasing resin content increased LE only 0.01 percent for the 30 to 90 percent RH condition and 0.02 percent for the WS and OD-VPS conditions. The effect of resin content on LE also depended on flaker type.

In general, as species density increased, LE based on OD-VPS and 30 to 90 percent RH increased, but LE based on WS decreased (Tables 8 and 10). If all species are averaged, the lathe-flake panels had the lowest LE values for all three test conditions (Table 8). The lathe-flake panels of all species expanded less under OD-VPS than panels made from flakes produced by the other flakers (table 10). Except for red oak panels, lathe-flake boards expanded less under the WS (Table 10). However, for 30 to 90 percent RH, loblolly pine was the only species with lowest LE among lathe-flake panels. Thus, to select the flaker that would yield the least LE, species and test conditions should be considered. But, generally, the lathe was best (less than 0.25 percent regardless of test conditions).

Thickness Swell (TS)

The largest amount of TS occurred under OD-VPS conditions (Table 8). An increase in resin content decreased TS by 3, 5, and 8 percent for 30 to 90 percent RH, WS, and OD-VPS conditions. The TS for the ring-flake panels after WS exceeded the TS of drum-flake panels. Otherwise, the order of increasing TS for all three conditions was the lathe-, disk-, ring-, and drum-flake panels.

As species density increased, a trend toward increased TS for OD-VPS was evident. In the WS, TS varied inversely with wood density. Under the 30 to 90 percent RH test, the species displayed a fairly uniform TS, with averages ranging from 13.4 percent for red oak to 14.3 percent for lodgepole pine. Red oak and hickory TS in the 30 to 90 percent RH test was higher than in the WS, but the reverse occurred for the other species. Generally, these trends were evident for each flaker (Table 10). Other than that, the lathe had the least TS for the three hardwoods based on OD-VPS, the best flaker for a particular species to yield a low TS depended on the test conditions.

Summary Comparisons

The densities of the species evaluated ranged from 23.7 pcf for lodgepole pine to 45.8 pcf for hickory. A compression ratio of 1.25 was attempted, but the actual compression ratio for the panels generally

decreased as species density incr general, panels of species with h ties had better MOR, MOE, and IB than less dense species. However density species generally had a g loss in these properties after ag loss may indicate bonding difficu high-density species or may be ca anatomical characteristics.

In table 11, the flakers wer based on data for the combined sp Properties were ranked from 1 (be then added to obtain a total valu two comparisons shown are based o ent test environments. The data that the disk and lathe flakers y flakeboards with similar properti overall, were better than the pro panels from the ring and drum fla

No flaker consistently yield with the best properties. If onl species and several properties we selected for analysis, a flaker c chosen that would yield a panel su panels produced by other flakers. an area where only one of the spe here or a species similar to it i a flaker could be selected that w superior to the others.

References

1. American Society for Testing a Materials. 1977. Standard method evaluating the properties of wood-fiber and particle panel materials ASTM Desig. D 1037-72a. ASTM, Philadelphia, Pa.

2. Heebink, B.G. 1967. A proced quickly evaluating dimensional sta of particleboard. For. Prod. J. 1 77-80.

Table 11.--COMPARATIVE RANKING OF FLAKERS.

Flaker	Initial Test			24-Hr. WS		Total Value	Final Ranking
	MOP	MOE	IB	LE	TS		
	------------- Psi ------------			------- % ---------			
	NO DRASTIC ENVIRONMENT TEST						
Ring	[1](2) 4,803	(3) 610,000	(1) 132	(3) 0.09	(4) 19.0	13	3
Disk	(2) 4,988	(1) 665,000	(2) 96	(1) .05	(1) 13.6	7	1
Lathe	(1) 5,565	(1) 685,000	(2) 104	(1) .04	(1) 13.2	6	1
Drum	(2) 4,706	(3) 629,000	(4) 87	(3) .09	(3) 17.2	15	3
	SEVERE ENVIRONMENTAL TEST						
Ring	(3) 3,684	(3) 480,000	(1) 34	(4) .31	(3) 29.5	14	3
Disk	(1) 3,934	(1) 530,000	(1) 33	(2) .28	(2) 26.3	7	1
Lathe	(1) 4,083	(1) 514,000	(3) 21	(1) .22	(1) 23.5	7	1
Drum	(3) 3,600	(3) 473,000	(3) 20	(2) .27	(4) 30.2	15	3

[1] Numbers in parentheses represent the property rankings.
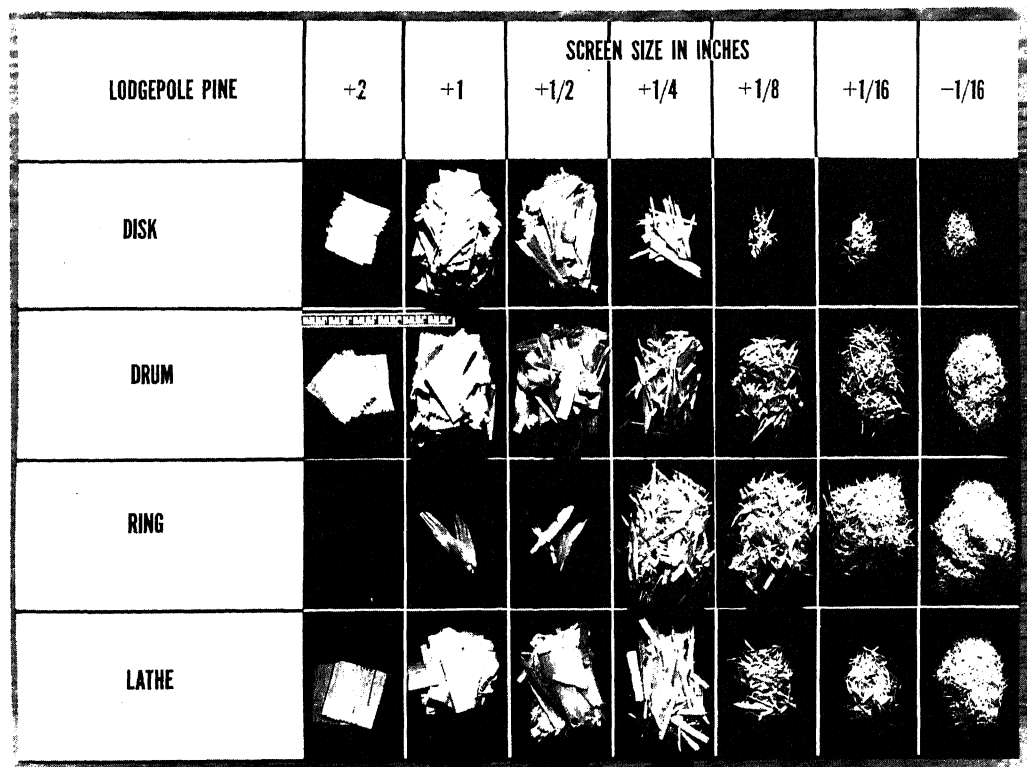
Figure 1.--Lodgepole flakes from each of four flakers shown as the weight percentage retained on each screen.
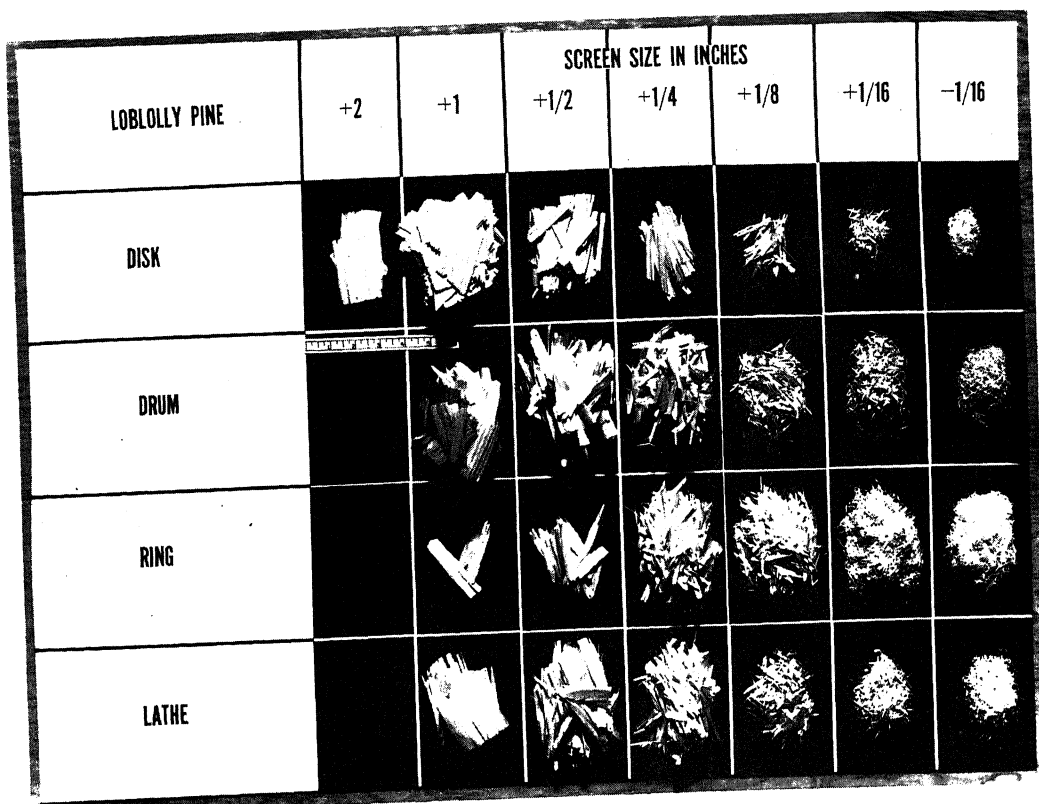
Figure 2.--Loblolly flakes from each of four flakers shown as the weight percentage retained on each screen.
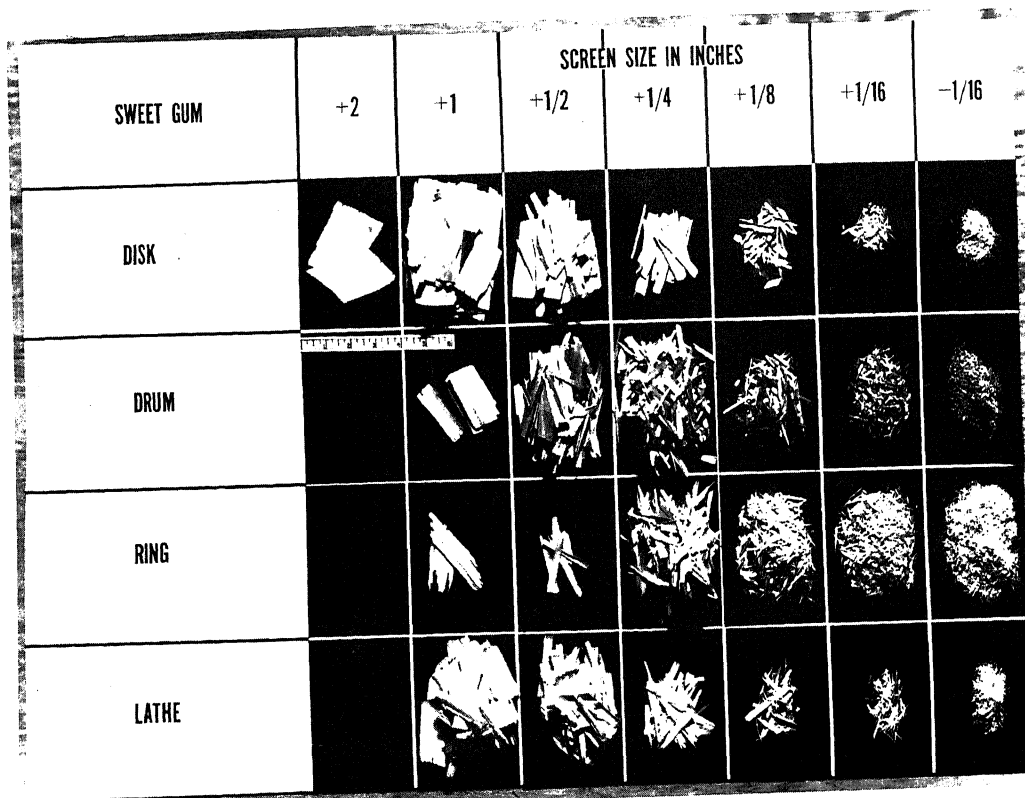
Figure 3.--Sweetgum flakes from each of four flakers shown as the weight percentage retained on each screen.
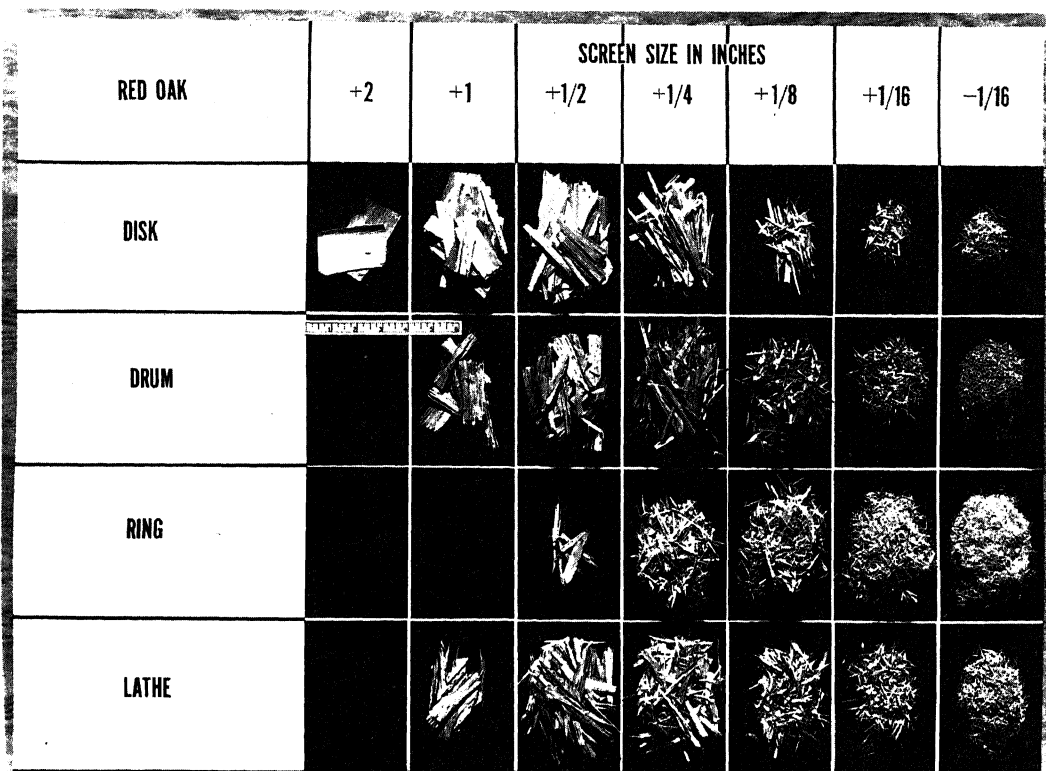
Figure 4.--Red oak flakes from each of four flakers shown as the weight percentage retained on each screen.
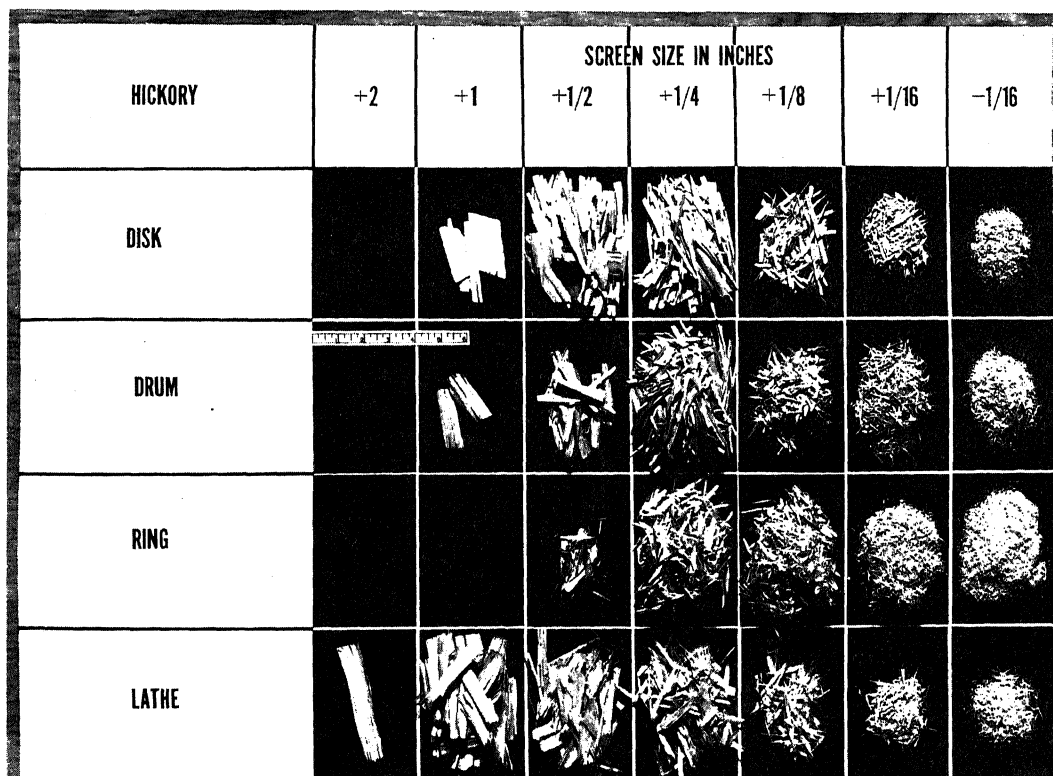
Figure 5.--Hickory flakes from each of four flakers shown as the weight percentage retained on each screen.
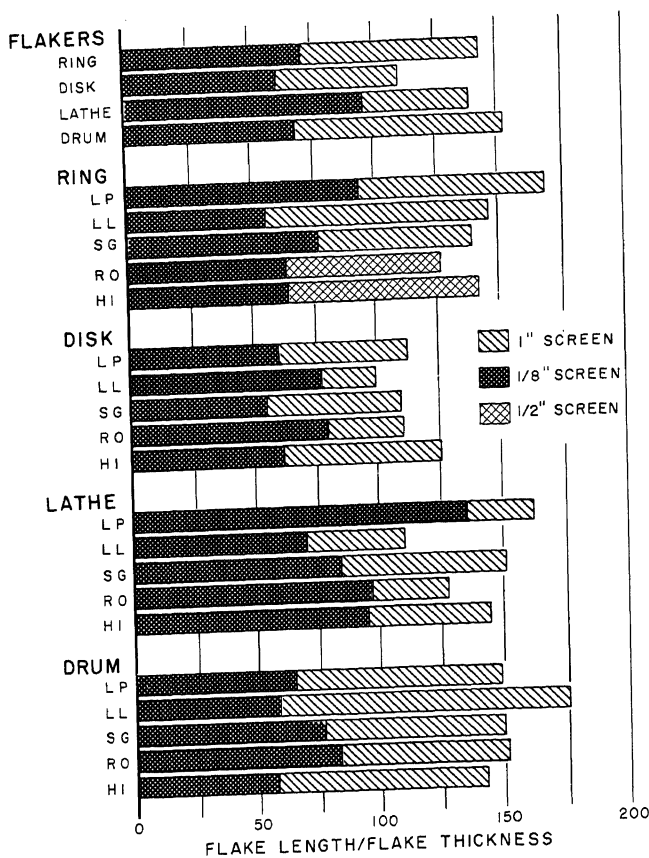
Figure 6. Ratio of flake length to flake thickness for lodgepole pine (LP), loblolly pine (LL), sweetgum (SG) red oak (RO), and hickory (HI) flakes cut on four flakers.

INITIAL TEST
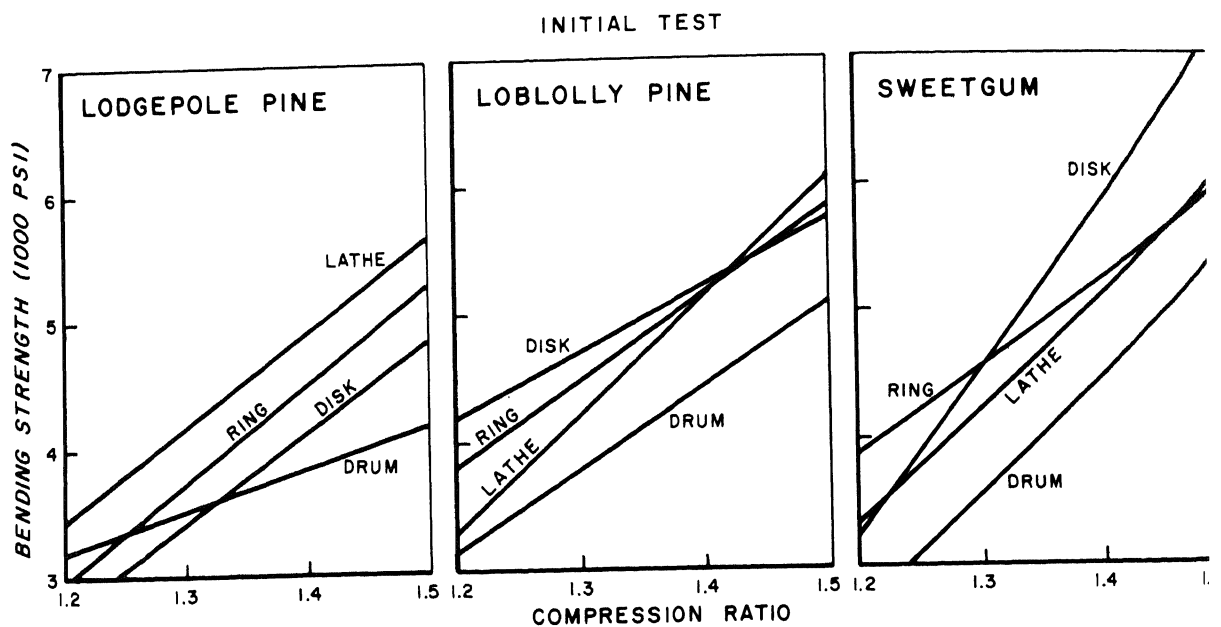
Figure 7. Bending strength and compression ratio relationship at 50% relative humidity for lodgepole pine, loblolly pine, and sweetgum panels made from flakes cut on four flakers.
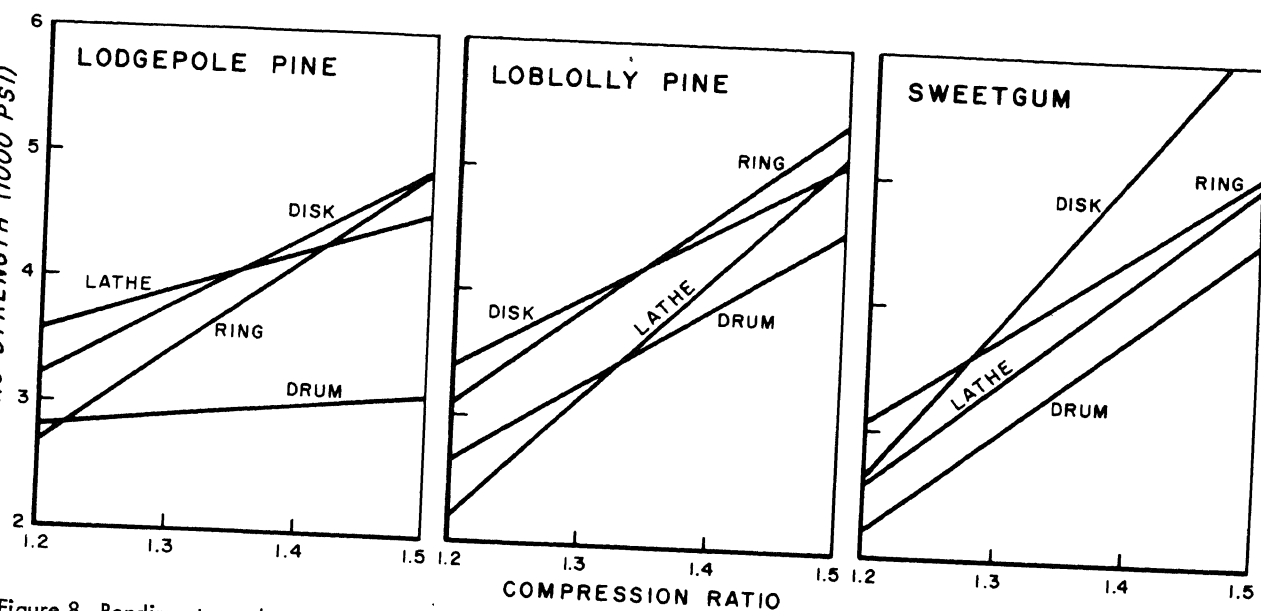
Figure 8. Bending strength and compression ratio relationship after accelerated aging cycle for lodgepole pine, loblolly pine, and sweetgum panels made from flakes cut on four flakers.
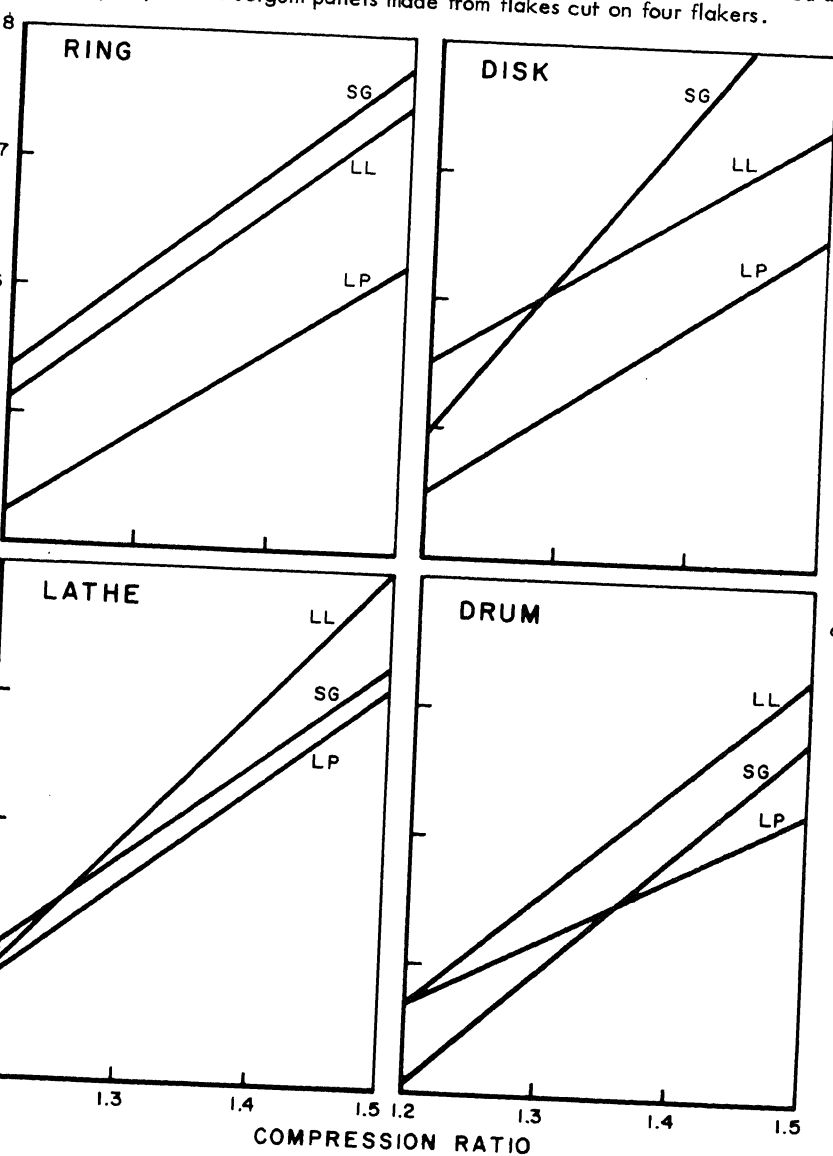
Figure 9. Modulus of elasticity and compression ratio relationship at 50% relative humidity for lodgepole pine (LP), loblolly pine (LL), and sweetgum (SG) panels made from flakes cut on four flakers.

63
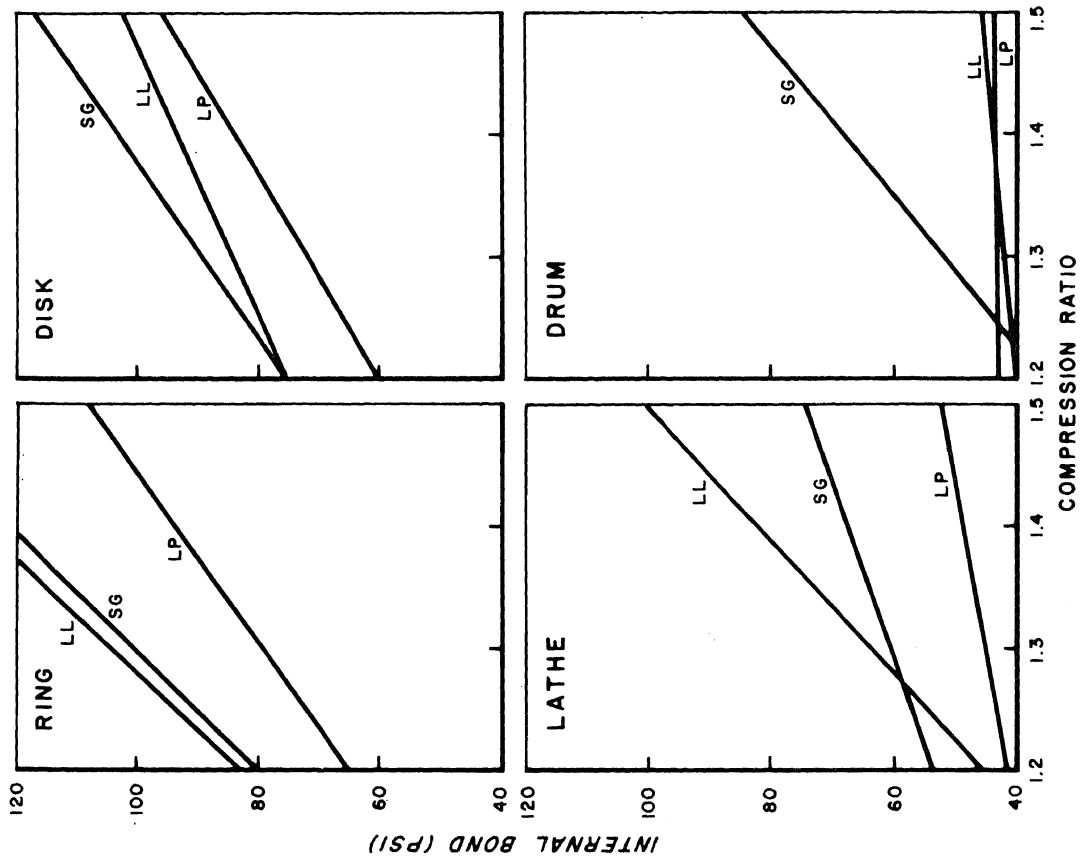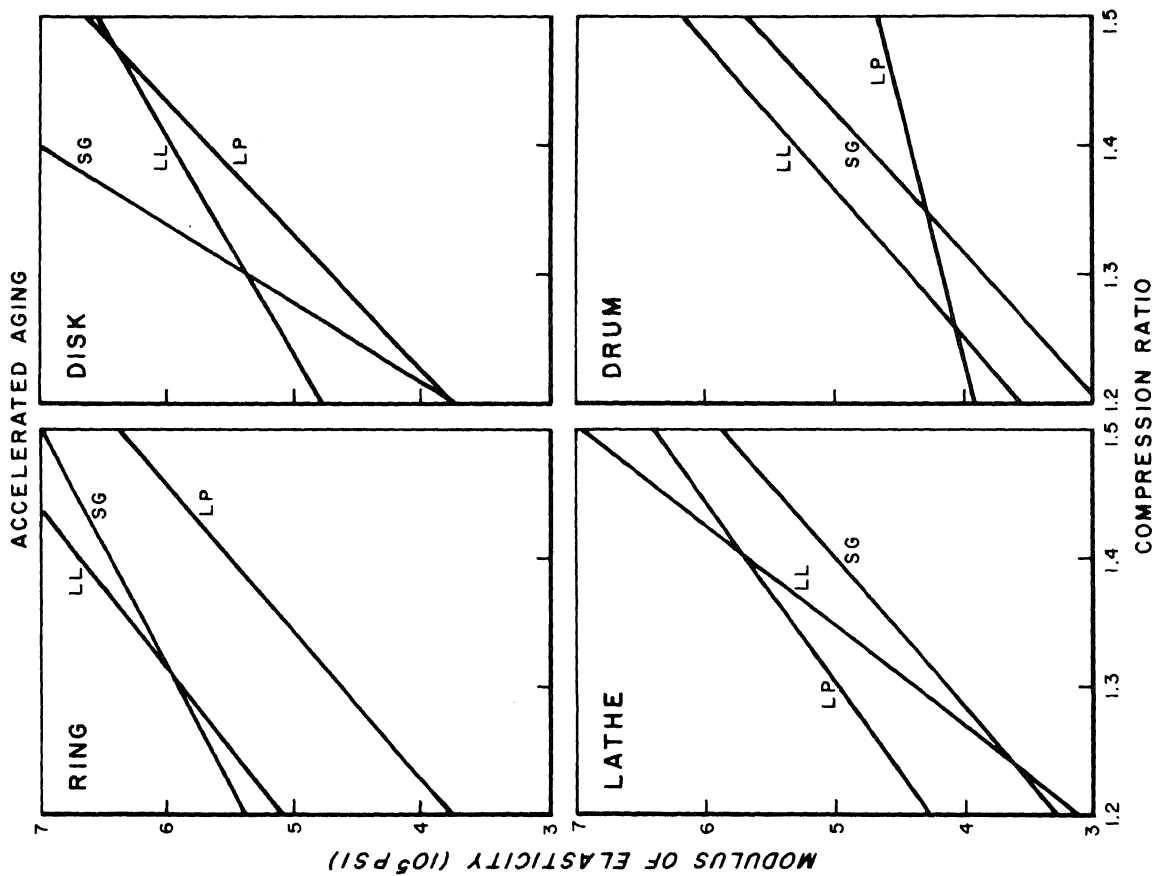
Figure 11. Internal bond and compression ratio relationship at 50% relative humidity for lodgepole pine (LP), loblolly pine (LL), and sweetgum (SG) panels made from flakes cut on four flakers.

64
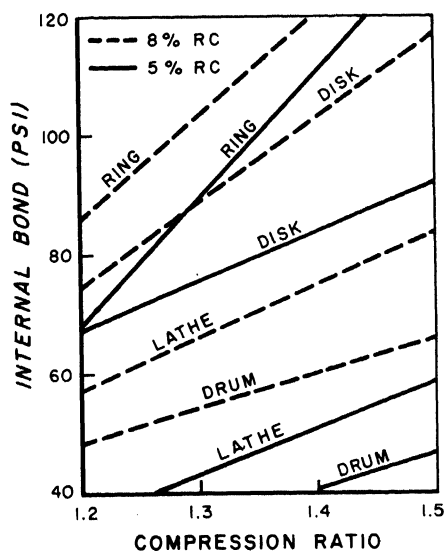
Figure 12. Internal bond and compression ratio
ratio relationship at 50% RH for the
average of three species--lodgepole pine,
loblolly pine, and sweetgum--and two resin
contents (5% and 8%). Panels were made from
flakes cut on four flakers.
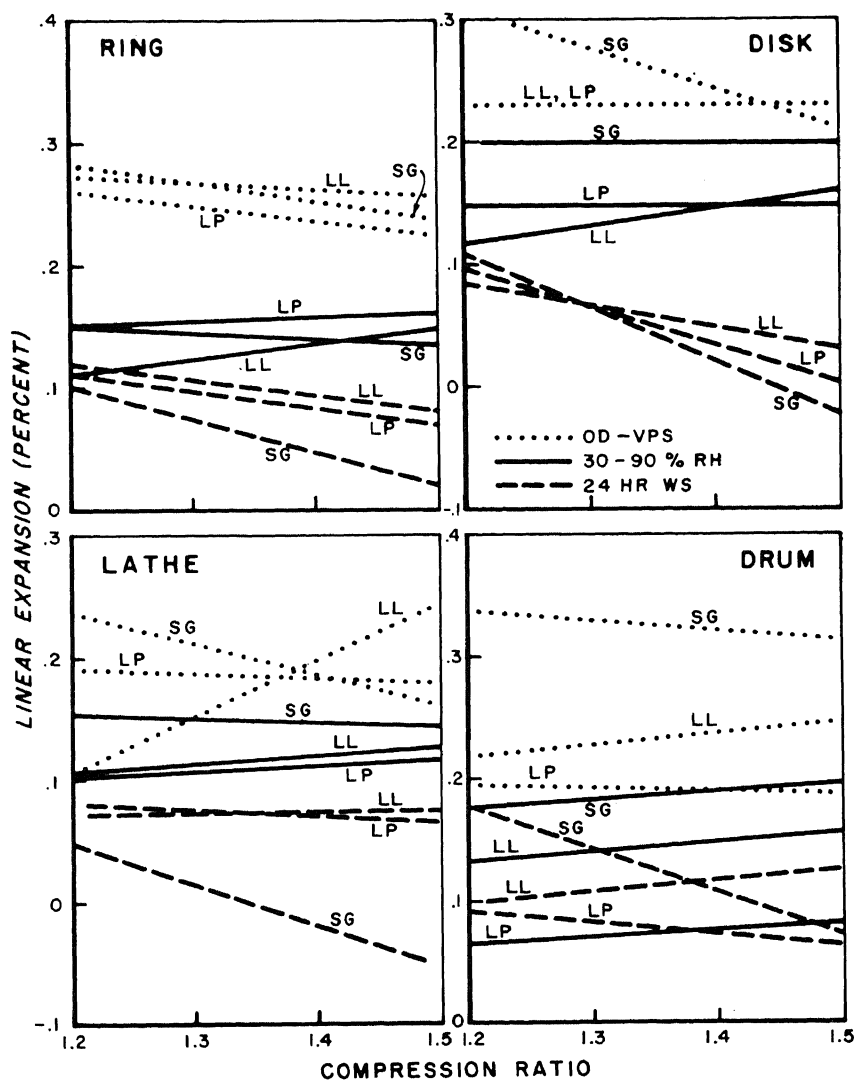
Figure 13. Linear expansion and compression ratio relationship for
lodgepole pine (LP), loblolly pine (LL), and sweetgum (SG) panels made
with flakes cut on four flakers.

Figure 14. Bending strength and compression ratio relationship for red oak and hickory panels made with flakes from four flakers. Panels fabricated at the target density of 52.6 pcf are accentuated.

BENDING STRENGTH (1000 P...)

RING
LATHE
DISK
RING
DISK
DRUM

LATHE
DISK
DRUM
RING
LATHE
DRUM

1.1   1.2   1.3   1.4   1.1   1.2   1.3

COMPRESSION RATIO

INITIAL TEST   ACCELERATED AGING

MODULUS OF ELASTICITY (10⁵ PSI)

—— RO
- - - HI

LATHE
LATHE
RING
DISK
RING
DRUM
● 52.6 pcf
TARGET DENSITY

LATHE
LATHE
RING
DISK
DRUM
DISK
RING
DRUM
● 52.6 pcf TARGET DENSITY

1.1   1.2   1.3   1.4   1.1   1.2   1.3   1.4
COMPRESSION RATIO

Figure 15. Modulus of el... and compression ratio re... ship for red oak and hi... panels made with flakes ... four flakers. Panels fa... at the target density o... pcf are accentuated.

INITIAL   ACCELERATED AGING

ALL FLAKERS

RING

DISK

LATHE

DRUM

[ ] 5 % RC
[ ] 8 % RC

75   125   175   225   275   0   20   40   60
INTERNAL BOND (PSI)

Figure 16. Effect of 5% and 8% resin content on the average internal bond of red oak and hickory combined. Panels were fabricated at a target density of 52.6 pcf with flakes generated from fou...

66

INITIAL TEST

RO
HI

RING

RING

LATHE

DRUM

DRUM

DISK

LATHE

DISK

ACCELERATED AGING

RO
HI

RING

DRUM

DISK

RING

LATHE

LATHE

DRUM

DISK

● 52.6 pcf TARGET DENSITY

COMPRESSION RATIO

Figure 17. Internal bond and compression ratio relationship for red oak and hickory panels made with flakes from four flakers. Panels fabricated at the target density of 52.6 pcf are accentuated.

THICKNESS SWELL (%)

DRUM
RING
DISK
LATHE
DRUM
RING
DISK
LATHE

RED OAK (38.3 pcf)
— 30-90% RH
--- OD-VPS

RING
DISK
LATHE
DRUM
LATHE
DISK
RING

HICKORY (45.8 pcf)

LINEAR EXPANSION (%)

DRUM
RING
DISK
LATHE
RING
LATHE
DRUM

RED OAK

DISK
LATHE
RING
DISK
DRUM
LATHE
RING

HICKORY

DRUM
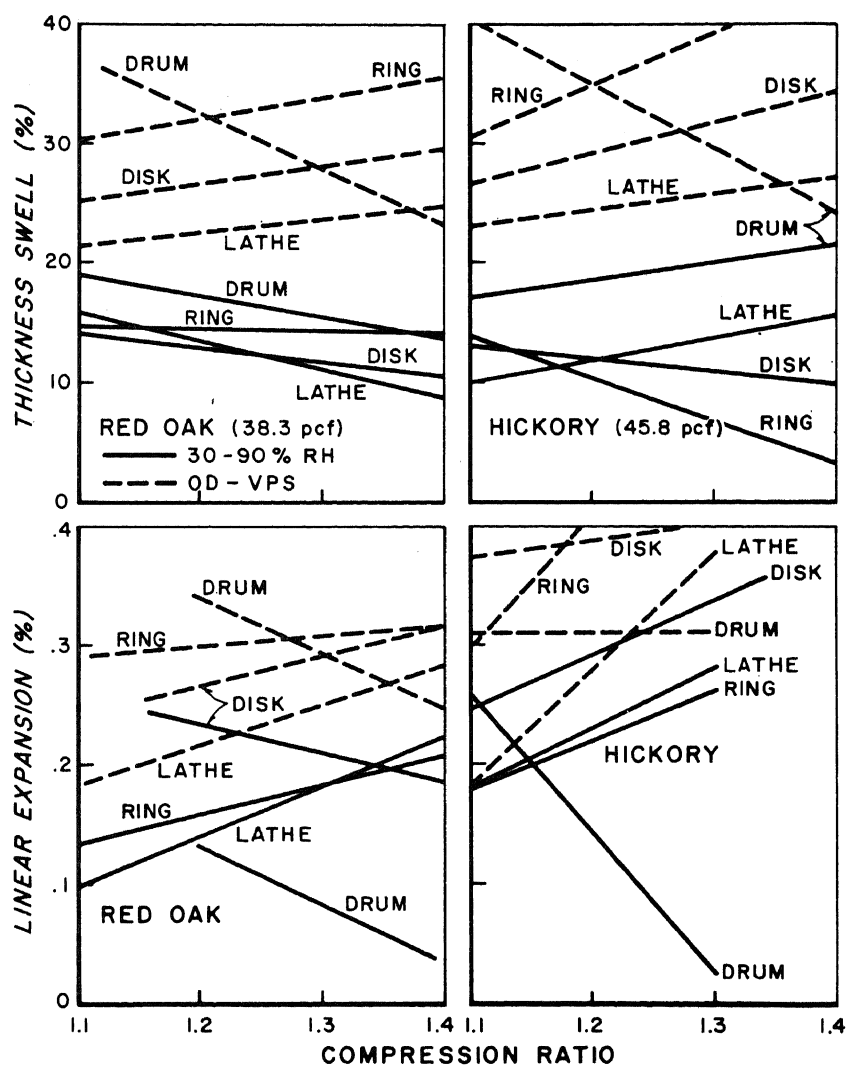
COMPRESSION RATIO

Figure 18. Dimensional properties (linear expansion and thickness swell) and compression ratio relationship for red oak and hickory panels fabricated with flakes from four flakers.

67
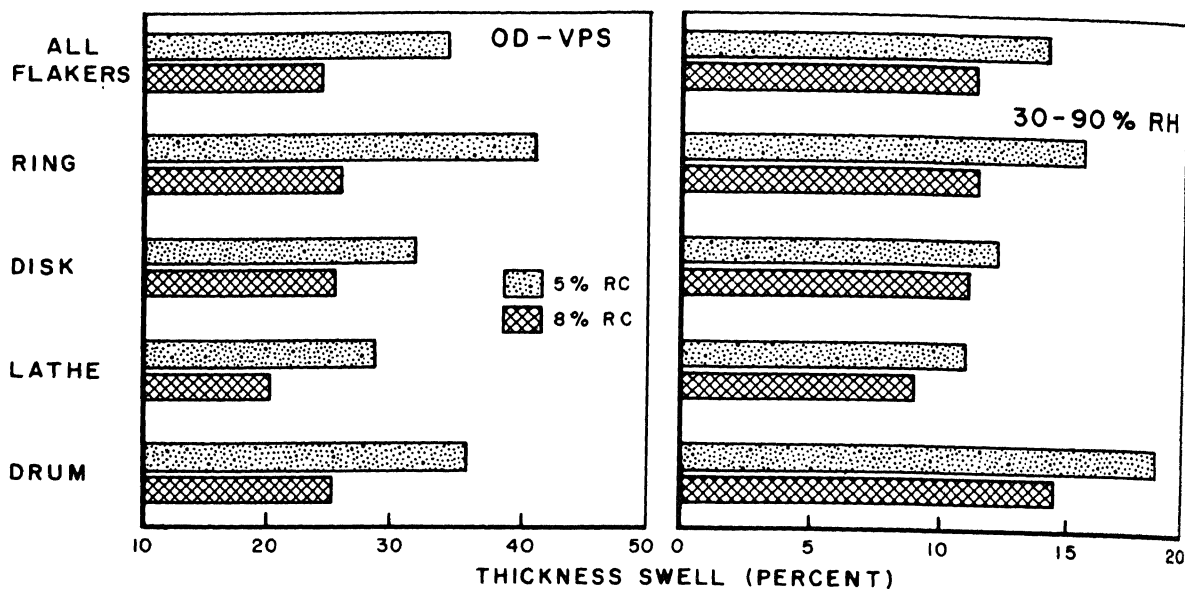
Figure 19. Resin content effect on the average percent thickness swell of red oak and hickory panels combined. Panels were fabricated at a target density of 52.6 pcf with flakes generated from four flakers.

CONSTRUCTION VARIABLES CONSIDERED IN FABRICATION
OF A STRUCTURAL FLAKEBOARD

R.L. Geimer
Technologist
Forest Products Laboratory
USDA Forest Service
Madison, Wisconsin

E.W. Price[1]
Technologist
Southern Forest Experiment Station
USDA Forest Service
New Orleans, Louisiana

Abstract

Flake geometry, flake quality, flake alignment, average density, density gradients, layer thicknesses, and resin content were factors considered in determining the final construction details on structural flakeboards made from 1) western softwoods and 2) southern hardwood residues. After making compromises between board properties, a three-layer design was recommended for both board types. Long, thin face flakes enhanced bending properties while thick core flakes maximized internal bond strengths.

The lower compaction ratio associated with high-density hardwood species restricted the range of the variables used, as compared to those considered by the softwood board. The use of high-quality surface flakes and a surface water spray were other methods used to improve the performance of the hardwood board. Alignment of face flakes substantially increased the bending properties in the aligned direction for both board types. Being bound on one hand by economics and on the other by strength and durability requirements, a liquid phenolic resin content of 5 to 6 percent was used for the binder. By carefully choosing construction variables and fabrication techniques, acceptable panels from forest and mill residues were recommended for structural application.

Introduction

The direction of research aimed at utilization of residues in structural boards is determined to a large extent by the form of the residue and the species involved.

The Southern Experiment Station, Alexandria, La., in attempting to economically utilize the smaller hardwood logs., has elected to derive the furnish for a structural board from flakes created on a shaping lathe headrig. A three-layer construction has been developed using long, thin flakes for the faces and thicker, narrower flakes in the core.

The Forest Products Laboratory on the other hand has been charged with making boards from softwood residue ranging in size from 4-foot-diameter logs to small branches (19). The softwood flakeboard is also of three-layer construction. Quality flakes cut from the larger residue,

on a disk-type flaker, are used for the face material. Smaller residues, after being chipped, are passed through a ring-type flaker to provide the furnish for the core of the board.

Many factors influence the properties of flakeboard. Construction variables such as board density, press closing speed, and mat moisture content will interact with each other, sometimes in a non-linear fashion, simultaneously to cause favorable and unfavorable reactions in different board properties. Furthermore, mechanical and economical factors such as machinability, resin content, and press time must be considered. Consequently, the choice of variables used (in constructing a flakeboard with structural characteristics) must be a compromise. Because of species effects, a wider range of variables is usually tolerable when using softwoods, than when using the high-density hardwoods.

Review of Major Variables

Flake Geometry

To meet the Forest Service performance goals of 800,000 psi average modulus of elasticity (MOE) and 4,500 psi near-minimum modulus of rupture (MOR) at reasonable board density levels, special attention was given to flake geometry. Numerous researchers have shown bending properties to increase directly with flake length and inversely with flake thickness (1,7,9,13,24,34). Improved bending performance has been shown for flake lengths up to 3 inches (28) and thicknesses as low as 0.006 inch (24).

Slenderness ratio (the relation of flake length divided by flake thickness) is a convenient way of combining these two variables. Slenderness ratios up to 300:1 have been shown to affect favorably bending properties (1,25,27) (Fig. 1). Below 1/2 inch, flake width is of minor importance in developing bending properties (4).

There appear to be limits at which the effects and interactions of all of these flake geometry variables cease to be important (4,9,16,34). A practical range from the standpoint of flake production, handling, and mat formation lies between 2 and 3 inches in length, 0.015 to 0.05 inch in thickness, and between 1/2 to 1 inch in width. In contrast to bending properties, internal bond strength (tension perpendicular to the surface)

increases as the flake thickness increases and flake width decreases(1,12, 18). Depending on particle configuration and relative size, decreasing flake length also increases internal bond (IB) (1). While the true significance of the IB property is not fully understood, it can be correlated to interlaminar shear (23) and is often used as an indicator of bonding quality and durability (the ability of a board to withstand accelerated aging).

Flake geometry affects durability by its influence on springback. Springback is the irreversible thickness swelling which occurs after wetting and is attributed to the release of stresses accompanied by some loss of glue bonds. As mentioned previously, increasing flake thickness improves strength properties perpendicular to the surface. Decreasing flake thickness, however, improves thickness swelling and linear expansion properties (1,18,24). Springback generally increases with an increase in flake thickness (18,25). The optimum flake thickness for durability and dimensional stability then becomes a compromise. Since the range of flake thickness in which significant improvements occur differs with each property and also depends to some extent on other flake dimensions, the optimum geometry is best found by empirical methods.

The effect of flake length on either durability or dimensional stability can also vary. Lehmann (18) found no connection between flake length and thickness swelling but did show reduced linear expansion in boards made from long flakes. Post (25) found springback increased with increasing flake length up to 2 inches but was drastically reduced with a 4-inch-long flake.

Other board properties such as edgewise shear and nail holdings also depend to some degree on flake geometry. However, no problem was encountered in meeting the goals and no effort was made to alter these properties by further manipulating the variables.

Flake Quality

The importance of flake quality in promoting resin efficiency and bond formation is shown in studies by Lehmann (18). Although quality is hard to define, the term is generally used to describe a furnish having flakes with smooth-cut surfaces and edges and possessing a minimum of fines.

The term is relative, of course, as shown by Price's (26) comparison of a veneer flake and a flake cut on a shaping headrig. While both types are considered to be quality flakes, the veneer flake has a decided advantage as indicated by IB tests. Quality can be enhanced by such practices as presoaking the logs in hot water. Heebink (8,10) and Maier (21) agree that a long chip (1-1/2 to 2-1/2 inches) will produce a better furnish when flaked in a ring flaker than the conventional 3/4-inch pulp chip. This is because the long chips align themselves with the grain parallel to the knives. Longer flakes with less cross grain and fines are produced.

While flake quality does affect internal bond directly (26), there seem to be strong interactions between quality, flake geometry, and bonding. Part of this interaction is due to resin efficiency (12,17), part due to differences in orientation of the particles with respect to the board thickness direction or orientation of the grain within the particles, and part attributed to conditions present in the core during bond formation.

Flake Alignment

The tremendous influence of flake alignment on increased board bending properties was investigated as early as 1952 by Klauditz (15). Other researchers have shown the extent of improvement with various flake types and degree of alignment (2,4,26,31). Using random orientation of ring-cut Douglas-fir for the core and aligned disk-cut face flakes at a face:core:face ratio of 15:70:15 percent, Ramaker and Lehmann (28) increased bending stiffness in the aligned direction by 73 percent and strength by 36 percent over a similar board with randomly distributed face and core flakes. The change of properties in one direction is, of course, made at the expense of those same properties in the opposite (90°) direction, (Fig. 2). Flake alignment does affect the dimensional stability of the board but has no effect on internal bond. Few data are available to show the effect of flake alignment on the various shear strengths (5).

Density

Increasing board density improves all the physical strength and stiffness properties. Comparison of density versus MOE for various species is well illustrated by Heebink (11) and Hse (12,13). Vital (35) has shown that the relationship between compaction ratio (board density divided by species density) and bending properties is independent of species mix. Internal bond is very sensitive to density (12,18,22). Nail-holding properties and hardness likewise depend to a great extent on board density. Research relating density to either thickness swelling or linear expansion is rather inconsistent. There appears to be some rather important interactions occurring between density, particle geometry, and bonding conditions which often tend to mask or even change the

fect of density. Density has been
own to affect the rate of change in
ickness swelling by controlling the
te of water absorption (29).

An important board characteristic
ressed by Kelly (14) is the density
adient which exists throughout the
ickness of hot-pressed boards. The
adient is controlled by a number of
ctors including press temperature,
ess closing time, mat moisture content,
d flake layer thickness (3,32,33),
ig. 3). Internal bond failures
nerally occur in the center line of
t-pressed boards because this is the
w-density region associated with the
rtical density gradient. Any con-
olled shifting of the density gradient
 favor bending characteristics de-
loped in the face layer necessarily
creases the core density and conse-
ently tends to lower IB.

yering

Since many of the boards' physical
operties depend on the characteristics
 a restricted area of the thickness
ne, it is advantageous to form a
yered board. By manipulating the
riables independently in the various
nes, board properties can be enhanced
re economically. Geimer et al. (3)
ve indicated that a face:core:face
tio of 15:70:15 will account for 52
 62 percent of the stiffness increase
ssible if the boards were made of all-
ce material. The thin face layers
so allow for a greater utilization of
or grade, smaller size residue in the
re, and permit flake alignment in the
ces independent from the core. Use of
three-layer construction technique
so permits utilizing different resin
vels or resin types in face and core.

sin Content

All boards made in the Forest Ser-
ce Structural Flakeboard From Forest
siduces Program used a phenol-formal-
hyde resin to achieve exterior dura-
lity performance. Increasing resin
ntent does improve all of the physical
operties (18,20,24).   The rate of
provement, however, varies with dif-
rent properties and optimum levels are
fected by particle geometry. MOE and
R increase only slightly if at all
ove 5 percent resin content (17,24,
).   IB levels continue to increase at
sin levels of 8 percent. Durability
 increased when the resin content is
ised from 3 to 9 percent (18,6).
ickness swelling as measured in relative
nidity conditions show various res-
nses to resin content levels dependent
 the test conditions and the particle
ometry. There appears to be an optimum
vel around 12 percent above which thick-
ss swelling again increases (30).
rticle geometry not only affects resin

efficiency but also controls curing rate.
Use of thick, coarse, but small particles
in the core material results in a more
porous core layer and provides for better
steam release during the pressing cycle,
which in turn aids the resin curing pro-
cess. The same high-porosity conditions
exist in low-density boards and partially
explains why internal bond and density
are often not well correlated.

Optimization of Variables

The effects of resin content, density,
flake thickness, and flake length on
bending stiffness (MOE) of homogeneous
Douglas-fir flakeboard are shown in
Figure 4. With 6 percent resin content,
MOE varied from a low of 402,000 psi
(0.045-inch-thick, 1/2-inch-long flake
and 37.5 pcf density board) to a high of
665,000 psi (0.030-inch-thick, 2-inch-
long flake and 42.5 pcf board). De-
creasing the flake thickness to 0.020
inch and increasing length to 3 inches
further increased the level of MOE at-
tainable in a homogeneous board to 800,000
psi (Fig. 5). The relative MOE level
attainable with 3-inch hardwood flakes
is also shown in Figure 5 and partially
reflects the differences between the
softwood and hardwood slenderness ratio
curves shown in Figure 1. It is readily
apparent that to meet the bending stiff-
ness goals a very high slenderness ratio
or high board density must be used with
the hardwoods. Work done at the Southern
Station indicates that a compaction ratio
of 1.185 is needed if the bending proper-
ties are to be met with a 0.015- by 3-
inch flake (Fig. 6). Using a specific
gravity of 0.639 for an average furnish
species, a board density of
47.5 pcf is necessary to attain the
800,000 psi MOE value.

Trial experiments with a three-
layer, 41 pcf Douglas-fir flakeboard
showed that an effective MOE of
760,000 could be obtained by using a
0.020- by 2-inch disk flake in the faces
and 0.050- by 2-inch ring flakes for the
core. By using a 0.020-inch-thick core
flake and a 3-inch-long face flake, MOE
increased to 865,000 psi (Fig. 7).

The possibility of using flake align-
ment to obtain rather large increases in
bending properties was also investigated.
Board stiffnesses were increased by 70 to
75 percent in the aligned direction using
Douglas-fir furnish (Fig. 8). Aligned
hardwood boards showed slightly smaller
bending stiffness increases, 44 to 57
percent, but were still dramatically
stiffer than a random configuration. The
effect of flake alignment on MOR proper-
ties was similar to that shown for MOE
(13,28).

Numerical differences in bending
properties of the three-layer boards

(Fig. 7) as compared to those homogeneous boards (Fig. 5) may be explained in part by a difference in density gradients. The rates of heat and moisture transfer during pressing and the resultant plastization of the furnish can be affected by the various layer combinations of face and core material (Fig. 9). Twelve percent mat moisture was used in constructing the three-layer boards, as compared to 10 percent mat moisture used in the homogeneous construction. Increased moisture will tend to increase the density gradient. The skin or I-beam effect is extremely important in achieving bending properties as shown by the rapid increase in MOE (tensile) experienced in face layer material at specific gravities exceeding 0.75 (Fig. 10). A water spray as used in constructing the hardwood structural boards will further promote a sharp density gradient approaching that shown for the fast press closure in Figure 3.

The effects of density, flake thickness, flake length, and resin contents on the internal bond property is shown in Figure 11. The relative magnitudes of the internal bond increase (Fig. 11) as opposed to the bending properties decrease (Fig. 7) with an increase in flake thickness was a major factor in using a thicker core flake. Additional internal bond increases were achieved with the hardwood lathe flakes by reducing the average flake width in a milling process. Data showed that an IB of 70 could be attained in the hardwood board at a comparison ratio of 1.15 (Fig. 6). With the five species mix under consideration this ratio corresponds to a density of 46.0 pcf.

The relative degree to which the different construction variables control dimensional stability is shown in Figures 12 and 13. Flake length has little effect on thickness swelling but does markedly control linear expansion. Reducing flake thickness decreases both TS and LE. Increasing density causes only a slight increase in either TS or LE, while increasing resin content from 3 to 9 percent affects a significant reduction in TS but reduces LE only slightly. The pattern of springback response to the variables is similar to that of thickness swelling (Fig. 14).

Retention of bending and IB properties following accelerated aging are shown in Figure 15 for a three-layer Douglas-fir board made using two densities and two resin content levels. The retention levels of MOE and MOR are based on measurements in the board's expanded condition but calculated on the initial thickness. This analytical procedure describes the board's retention of initial load-carrying capacity rather

than change in the material. The internal bond data on the other hand are directly related to density and consequently reflects the influence of springback. Whereas resin content has little to do with retention of the bending properties as calculated, lowering resin levels from 7 to 5 percent considerably reduces IB retention.

Final choice of the variables used to manufacture large, 1/2-inch-thick panels is given in Table 1. Analysis of the above referenced data can aid in further manipulation of the variables to achieve board property levels desired for specific structural applications.

Summary

In an attempt to maximize those board properties generally accepted as critical for structural purposes, compromises were made in arriving at optimum construction variables. The compaction ratio (board density:species density) effect had considerable influence in determining the parameters used for hardwoods as opposed to those developed for the softwood species. Average density levels of 40 to 42 pcf appeared as optimum in Douglas-fir laboratory panels while panel density was increased to 47.5 pcf for the hardwood boards. Economics and durability were the major criteria for establishing the resin level at 5 to 6 percent.

Face flake geometry and quality are largely responsible for attaining bending properties. A slenderness ratio (flake length:flake thickness) of 100 was used with the Douglas-fir boards while a ratio of 200 was used with the hardwood boards. Steep vertical density gradients, favorable to bending properties, were achieved in both boards by using a fairly rapid press closing of (3/4-1 min.) A surface water spray further increased the density gradient in the hardwood panels.

Use of long but thick and narrower flakes in the core promoted internal bond properties with a minimum reduction in bending characteristics. Dimensional stability and bending durability characteristics were adequately obtained with the selected variables. Retention of internal bond strengths following aging were marginal but could be improved with additional resin. No problem was encountered in meeting goal specification for nail pull-through, nail withdrawal, or the various tension, compression, and shear properties; as such, they were not considered directly in optimizing the variables. Studies were extended to establish the practical limit of strength and other property improvements attainable with further manipulation of the variables. Flake alignment proved to be a method of achieving high bending properties (well

over a million psi) in the critical
aligned direction.

References

1. Brumbaugh, J. 1960. Effect of flake
dimensions on the properties of particle-
boards. For. Prod. J. 10(5):243-246.

2. Elmendorf, H. 1965. U.S. Patent
3164511. June 5.

3. Geimer, R., Montrey, H., and Lehmann,
W. 1975. Effects of layer characteris-
tics on the properties of three-layer
particleboards. For. Prod. J. 25(3):
19-29.

4. Geimer, R. 1976. Flake alinement in
particleboard as affected by machine
variables and particle geometry. USDA
For. Serv. Res. Pap. FPL 275. For.
Prod. Lab., Madison, Wis.

5. Geimer, R., Lehmann, W., and McNatt,
J. 1974. Engineering properties of
structural particleboards from forest
residues. Proc. 11th WSU Particleboard
Symp. Washington State Univ., Pullman,
Wash.

6. Hann, R.A., Black, J.M., Blomquist,
R.J. 1963. How durable is particle-
board II, The effect of temperature and
humidity. For. Prod. J. 13(15):169-174.

7. Heebink, B., and Hann, R. 1959.
How wax and particle shape affect
stability and strength of oak particle-
boards. For. Prod. J. 9(7):197-203.

8. Heebink, B. and Dominick, R.M.F. 1971.
Forest residues: Future source of
particleboard? Wood and Wood Products
76(11): 26-28.

9. Heebink, B. 1974. Particleboards
from lodgepole pine forest residue.
USDA For. Serv. Res. Pap. FPL 221.
For. Prod. Lab., Madison, Wis.

10. Heebink, B., Schaffer, E., Chern, J.,
and Haskell, J. 1977. Structural flake-
boards using ring flakes from fingerling
chips. USDA For. Serv. Res. Pap. FPL
296. For. Prod. Lab., Madison, Wis.

11. Heebink, B. and Lehmann, W. 1977.
Particleboards from lower grade hardwoods.
USDA For. Serv. Res. Pap. FPL 297. For.
Prod. Lab., Madison, Wis.

12. Hse, Chung-Yun. 1975. Properties of
flakeboards from hardwoods grown on
Southern pine sites. For. Prod. J. 25(3):
48-53.

13. Hse, C., Koch, P., McMillin, C., and
Price, E. 1975. Laboratory scale
development of a structural exterior
flakeboard from hardwoods grown on
Southern pine sites. For. Prod. J.
25(4):42-50.

14. Kelly, M. 1977. Critical literature
review of relationships between processing
parameters and physical properties of
particleboard. USDA For. Serv. Gen.
Tech. Rpt. FPL-10. For. Prod. Lab.,
Madison, Wis.

15. Klauditz, W.G., Stegman, G., Boro, A.,
Kratz, U., and May, H. 1965. Research
and developments in construction materials
made from wood particles: techniques for
producing wood-chip or compound materials
with directional strength. Forschungsber
Des Landes Nordrhein, Westfalen, Koch
No. 1520, p. 47.

16. Kusian, R. 1968. Modern investiga-
tions about the influence of particle size
on structural and strength properties of
particle materials: Experimental in-
vestigations. Holz Technologie 9(4):
241-48.

17. Lehmann, W.F. 1970. Resin efficiency
in particleboards as influenced by density
atomization and resin content. For. Prod.
J. 20(11):48-54.

18. Lehmann, W.F. 1974. Properties of
structural particleboards. For. Prod. J.
24(1): 19-26.

19. Lehmann, W.F. and Geimer, R. 1974.
Properties of structural particleboards
from Douglas-fir residues. For. Prod.
J. 24(10):17-25.

20. Lehmann, W.F. 1974. Durability of
composition board products. Proc. 11th WSU
Particleboard Symp. Washington State
Univ., Pullman, Wash.

21. Maier, G. 1977. Effects of chip
shape on the flake quality in producing
flakes from chips. Holz Roh Werkst.
35:365-367

22. McMillin, C. and Koch, P. 1973.
Final report - Properties of homogeneous
exterior structural boards made from
southern hardwood or loblolly pine flakes
cut on a Koch lathe. USDA For. Serv.
Southern For. Exp. Sta., Alexandria, La.
[Unpublished]

23. McNatt, J.D. 1973. Basic engineering
properties of particleboard. USDA For.
Serv. Res. Pap. FPL 206. For. Prod. Lab.,
Madison, Wis.

24. Post. 1958. The effect of particle
geometry and resin content on bending
strength of oak particleboard. For. Prod.
J. 8(10):317-322.

25. Post. 1961. Relationship of flake
size and resin content to mechanical and
dimensional properties of flakeboard.
For. Prod. J. 11(1):34-37.

26. Price, E. and Kesler, C. 1974.
Analysis of southern hardwoods as furnish
for a wood flake-resin composite structural

of Illinois, Urbana, Illinois.
Report USDA 19-130.

27. Rackwitz. 1963. Influence of chip
dimensions on some properties of wood
particleboard. Holz Roh-Werkst 21(6):
200-209.

28. Ramaker, T., and Lehmann, W. 1976.
High performance structural flakeboards
from Douglas-fir and lodgepole pine
forest residues. USDA For. Serv. Res.
Pap. FPL 286. For. Prod. Lab., Madison,
Wis.

29. Roffael, E., and Rauch, W. 1972.
Influence of density on the swelling
behavior of phenolic resin bonded
particleboard. Holz Roh-Werkst 30(5):
178-181.

30. Schuler, C.E. 1974. Pilot study of
the use of pulpwood chipping residue for
producing particleboard in Maine. Tech.
Bull. No. 67 Life Sci. and Agr. Exp. St.
Univ. of Maine, Orono.

32. Suchsland, O. An analysis of the
particleboard process. Quarterly
Bulletin, Mich. Agric. Exp. St. 42(2):
350-372. Mich. State Univ.,East Lansing.

33. Suchsland, O. 1960. An analysis of
a two species, three-layer wood flake-
board. Quarterly Bulletin, Mich. Agric.
St. 43(2): 375-393. Mich. State Univ.,
East Lansing.

34. Turner, D. 1954. Effect of particle
size and shape on strength and dimen-
sional stability of resin bonded wood
particleboards. For. Prod. J. 4(5):
210-222.

35. Vital, B., Lehmann, W., and Boone,
R.S. 1974. How species and board
densities affect properties of exotic
hardwood particleboards. For. Prod. J.
24(12): 37-45.

Table 1.--VARIABLES CHOSEN TO MANUFACTURE 1/2 INCH BY 4- BY 8-FOOT
STRUCTURAL FLAKEBOARD PANELS FROM FOREST RESIDUES

Manufacturing Variables	Softwood	Hardwood
Raw material	Douglas-fir residues	Equal amounts of white oak, hickory, southern red oak, sweetgum, and southern pine
Panel density	43 pcf[1]	47.5 pcf[2] random, 45.5 pcf[2] alined
Face flakes	0.02 x 1 x 2 in disk flakes	0.015 x 3 in x random width shaping headrig flakes, bolts heated to 160°F
Core flakes	0.05 x 2 in x random width ring flakes	0.025 x 3 in shaping headrig flakes, milled to reduce width
Face:core:face flake ratio	15:70:15 by weight	25:50:25 by weight
Phenolic resin	5% solids[3]	6% solids[3]
Wax emulsion	1% solids[3]	1% solids[3]
Mat moisture content	10%	10%, addition 4.32 g of water/ft^2 sprayed on surface
Press cycle	10 min at 350°F Press closed to stops in 1 min	5 min at 350°F Press closed to stops in 3/4 min

[1] Based on oven dry weight and nominal volume.

[2] Based on 6% panel moisture content.

[3] Based on oven dry weight of flakes.
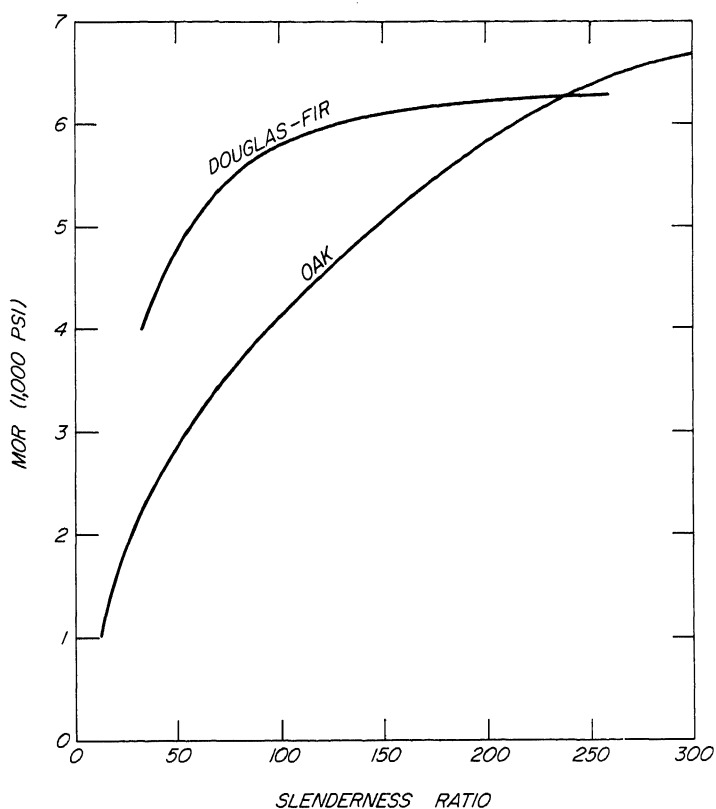
Figure 1.-- Slenderness ratio (flake length/flake thickness) vs.
modulus of rupture (MOR). Douglas-fir values are
from Brumbaugh (1); oak figures from Post (24).
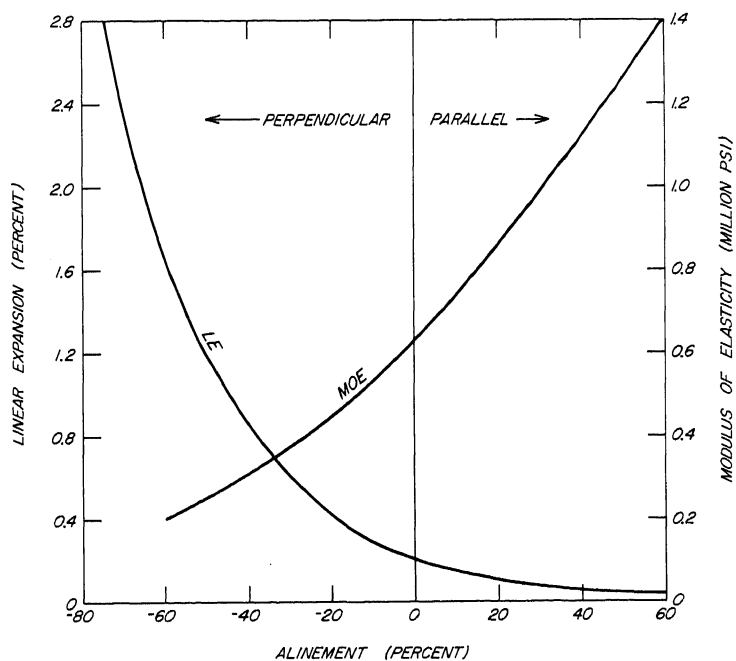
Figure 2.-- Percent of flake alignment vs. linear expansion (LE)
and modulus of elasticity (MOE). From Geimer (4).
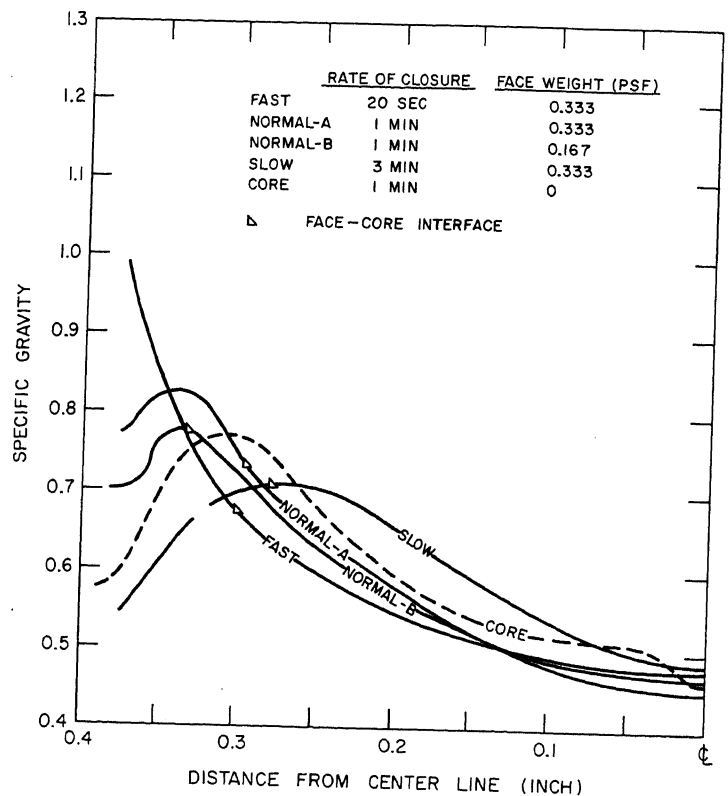
Figure 3.-- Density gradient for 3/4-inch particleboards as
affected by rate of closure and face weight. From
Geimer et al. (3).
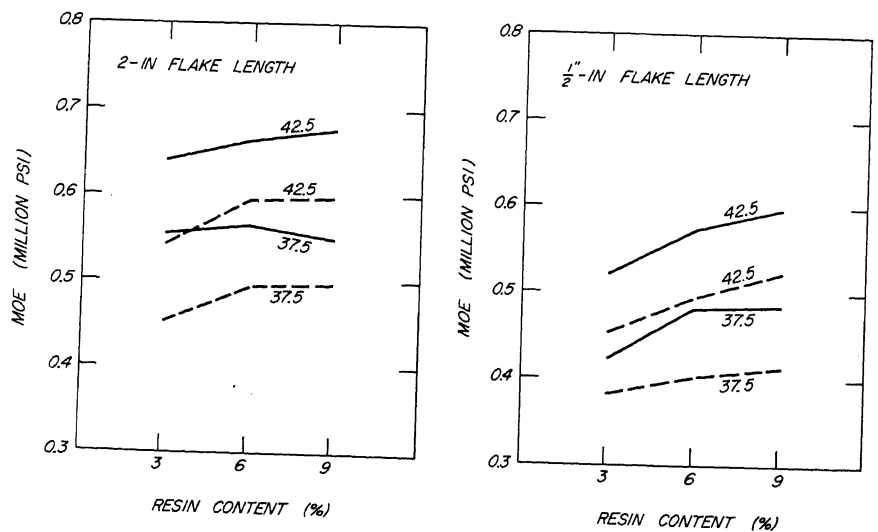
Figure 4.-- Effect of resin content, density, flake thickness,
and flake length on MOE. Values from Lehmann (18)
with data adjusted to densities of 37.5 or 42.5 pcf.
Solid lines depict data from board made with 0.030-
inch-thick flakes; dashed lines refer to 0.045-inch-
thick flakes.
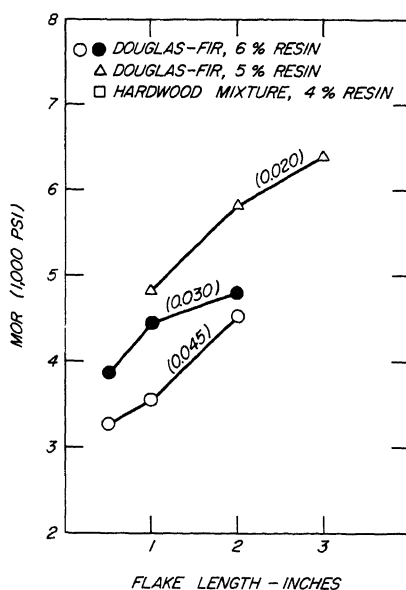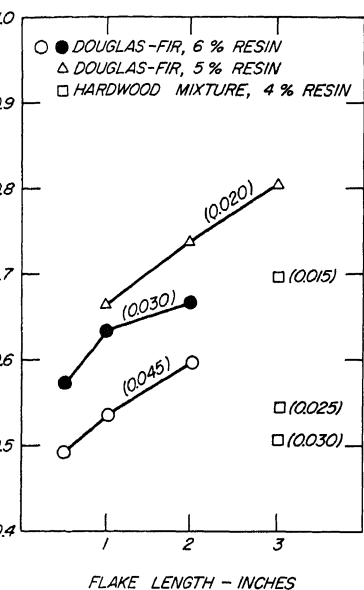
Figure 5.--Effect of flake
length and flake thickness
on modulus of elasticity
(MOE) and modulus of rup-
ture (MOR). Number in
parenthesis is flake thick-
ness in inches. Values for
Douglas-fir 6% resin solids
are from Lehmann(18);
Douglas-fir 5% resin solids
from Geimer(4); hardwood
mixture 4% resin solids
from McMillan and Koch(22).
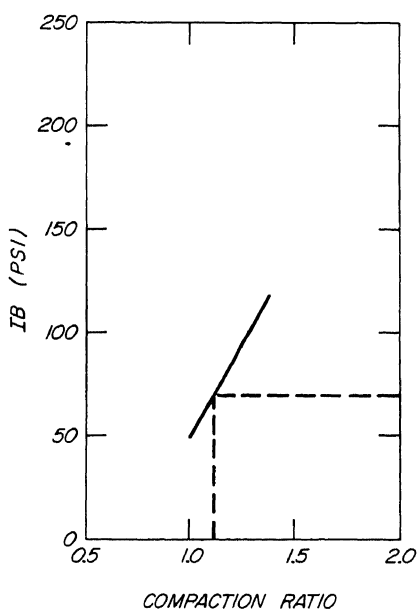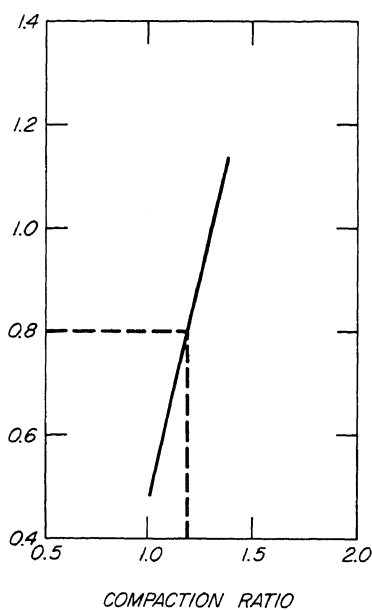
Figure 6.-- Minimum compac-
tion ratio required to
achieve the FS goal of
800,000 psi MOE and 70 psi
IB using the hardwood mix.
Dotted line shows ratio of
1.18 for MOE and 1.15 for
IB.   Lathe flakes 0.15 and
3 inches are from an equal
mixture of four hardwoods
and southern pine, from
Hse (13).
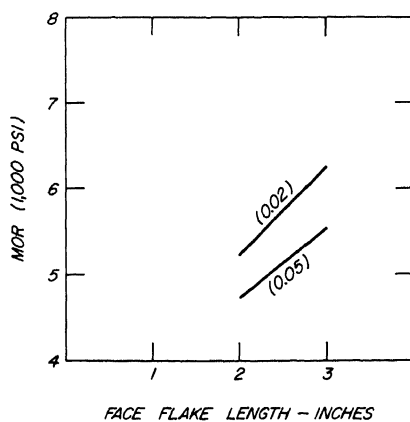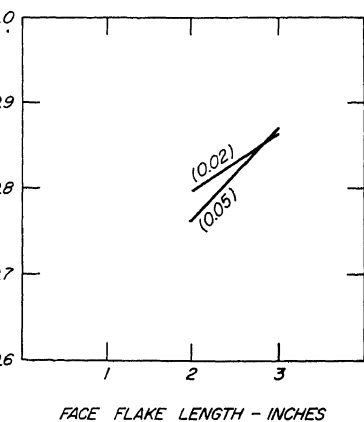
Figure 7.-- Effect of core
flake thickness and face
flake length on MOE and MOR
of three-layer structural
flakeboard. Numbers in
parentheses are core flake
thicknesses in inches.
Values are from Ramaker(28).
0.020-inch face flakes
12% face MC, 8% core MC
15:70:15%, face:core:face
   ratio
5% PF resin
Av. panel density 41.0 pcf.
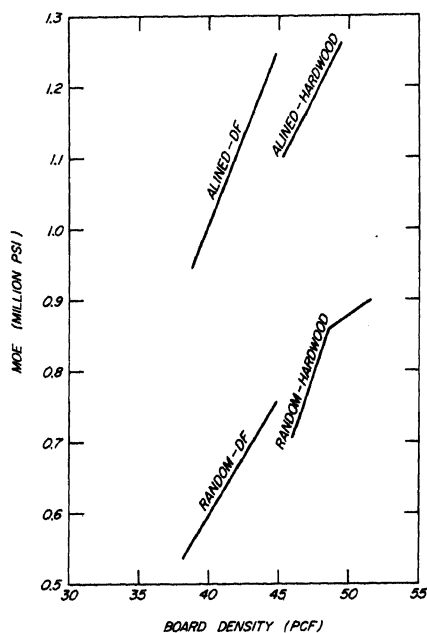
Figure 8.--Effect of density and alignment on MOE of three-layer boards. Values for Douglas-fir (5% resin solids) are from Ramaker (28); values for hardwood mix (5.5% resin solids) are from Hse(13).

FACE WEIGHT (PERCENT OF TOTAL WE...
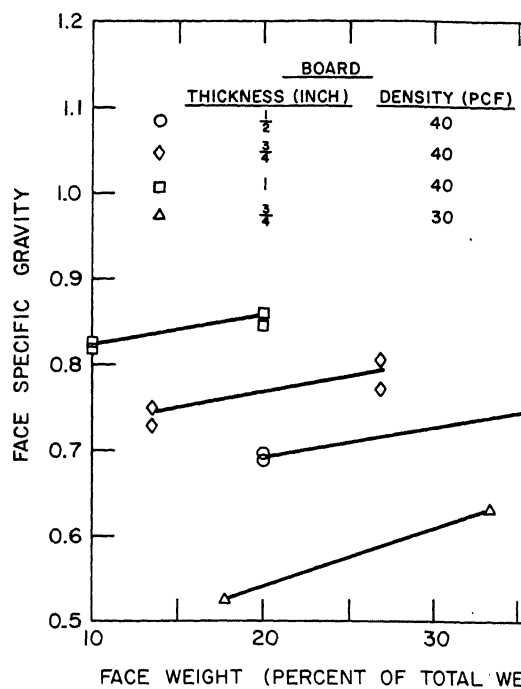
Figure 9.-- Face layer specific grav... affected by face weight and total bo... thickness. From Geimer et al. (3).

Figure 10.-- Influence of specific gravity on the MOE (tensile) and total board thickness. From Geimer et al. (3).
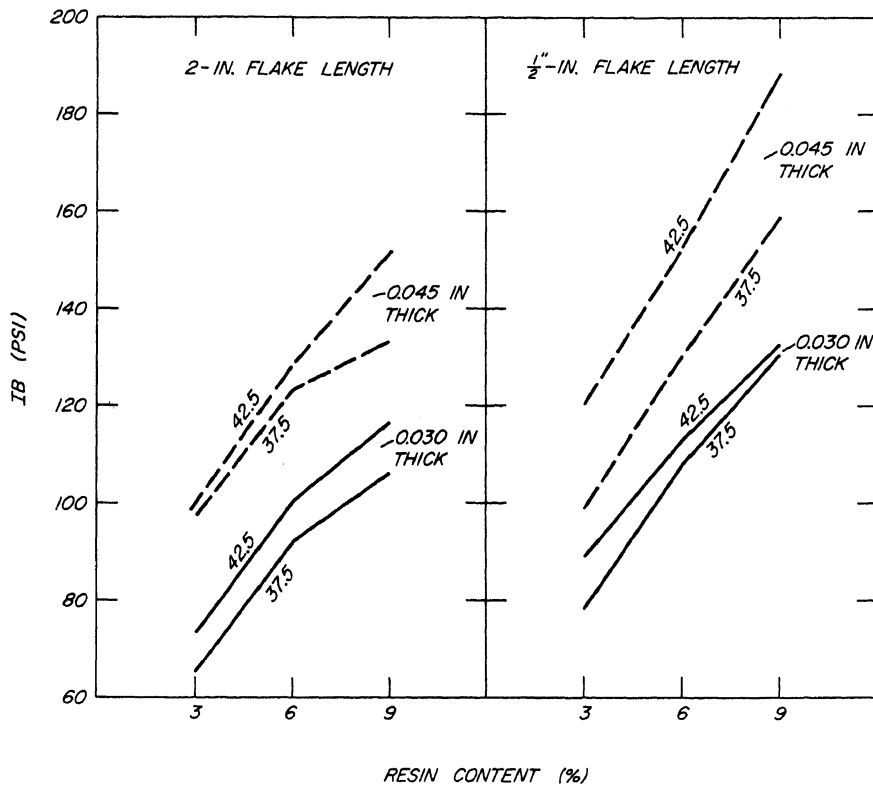
Figure 11.-- Effect on internal bond of resin content and density, two flake thicknesses, and two flake lengths. Values are from Lehmann (18).
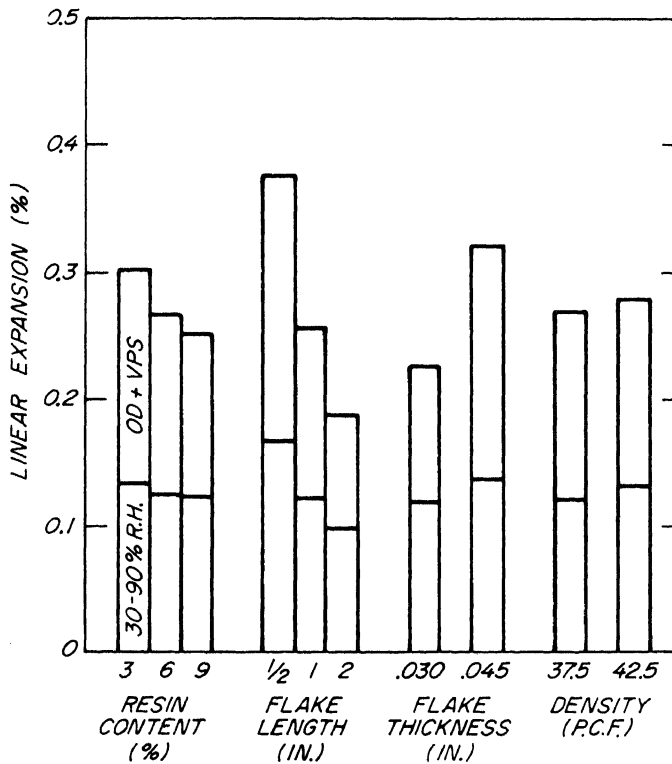
Figure 12.-- Overall effects of variables on linear expansion of Douglas-fir flakeboards in 30 to 90% RH and ovendry and vacuum-pressure-soak tests. Values are averaged across the other variables. From Lehmann (18).

79
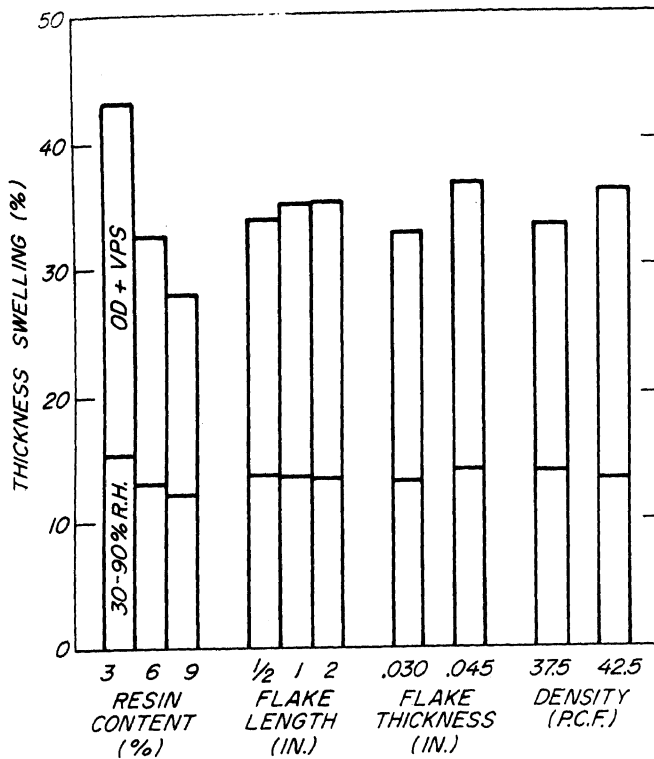
Figure 13.-- Overall effects of
on thickness swelling of flakeb
30 to 90% RH and ovendry and va
pressure-soak tests. Values ar
across the other variables. Fr
Lehmann (18).

Figure 14.-Overall effects of study
variables on thickness swelling reten-
tion of flakeboards after steam post-
treatment and/or accelerated aging
exposure. Values are averaged across
the other variables. From Lehmann (18).
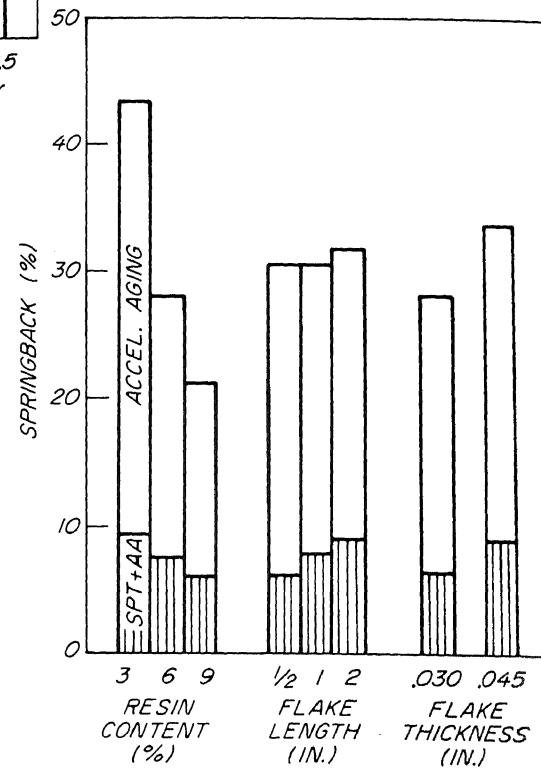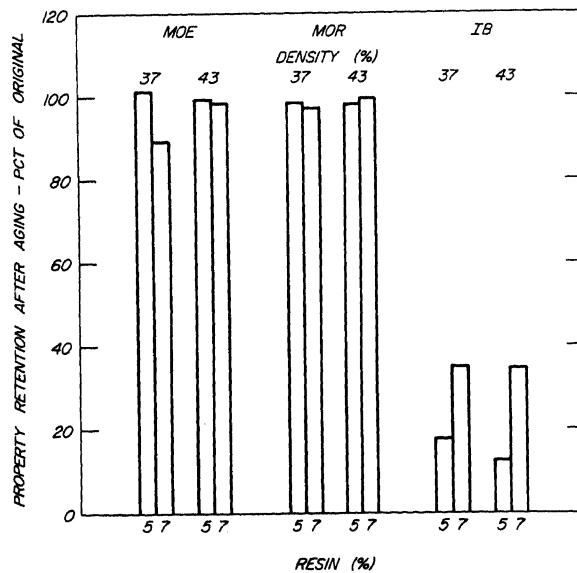
Figure 15.-- Retention of prope
following accelerated aging
(ASTM D 1037). Values are fro
Ramaker (28).

DEVELOPMENT OF A RESIN SYSTEM FOR
GLUING SOUTHERN HARDWOOD FLAKEBOARDS

Chung-Yun Hse[1]
Principal Wood Scientist
Southern Forest Experiment Station
USDA Forest Service
New Orleans, Louisiana

Abstract

A series of experiments was conducted
develop an effective economincal resin
tem for gluing flakeboard of mixed
thern hardwoods. First, a phenolic
in was formulated with a second
maldehyde addition at reaction con-
tration of 47.5 percent and reaction
perature of 95°C. Such resin yielded
isfactory bonds in laboratory boards
e of mixed hardwoods with 1) a minimum
in content of 4 percent, 2) a minimum
 press time of 4 minutes, 3) a maximum
 moisture content of 14 percent, and
a hot press temperature of 325°F. The
ects of board and wood density on bond-
 strength may best be expressed by
ke compaction in the panel. Board
ength increases in proportion to com-
tion ratio (i.e., the ratio between
rd density and wood density). Because
h-density flakes require higher panel
sity than low density flakes to attain
adequate compaction ratio, boards of
h-density species tend to be exces-
ely heavy.

To produce a flakeboard of acceptably
v density from wood of many species
d densities, a phenolic alloy of phenol-
rmaldehyde resin and polyisocyanate was
veloped. The key to this alloying
ocess is first applying minor amounts
polyisocyanate before application of
jor amounts of phenolic resin on wood
rnish, and then reacting the combined
esive in situ to obtain an improved
ermosetting adhesive resin suitable for
rdwood flakeboard. The performance of
e new phenolic alloy is superior to
at of phenolic resin under high flake
isture content, low resin content, and
v panel density.

Introduction

This paper is one of a series de-
ibing efforts of the Pineville,
isiana, Laboratory of the Southern
st Experiment Station to develop an
ective economical resin system for
ing hardwood flakeboard of mixed
thern species. The study is a se-
ice of three experiments: 1) formula-
n of an economical fast-cure phenolic
in for exterior hardwood flakeboard;
gluing properties of flakeboards from
dwoods growing on southern pine sites;
3) development of a new adhesive
em to improve glue bond of hardwood
keboard.

---

tioned at Pineville, La.

Experiment 1. Formulation of an
Economical Fast-cure Phenolic Resin

Phenolic resins are excellent ad-
hesives for exterior plywood and can
readily be used to make exterior flake-
board resin. Optimum viscosity of a
flakeboard resin, however, is considerably
lower than that of the conventional ply-
wood resin. Consequently the resin for
flakeboard requires a longer press time
to cure completely than plywood resin
(i.e., 8 to 10 minutes for flakeboard
resin, 3 to 5 minutes for plywood resin).
To reduce press time, a phenolic resin
must have maximum chemical reactivity.

Optimizing Reaction Concentration

Bond quality of plywood specimens
made with different resins revealed that
the following formulation variables for
phenolic resins are best (3):

Formaldehyde to phenol molar ratio
of 1.8 to 1.9
Sodium hydroxide to phenol molar
ratio of 0.4 to 0.5
Reaction concentration, an undeter-
mined number greater than 43 percent.

Although results from plywood speci-
mens are not strictly applicable to
flakeboard resins, they provide a starting
point for further refining of formulation
variables. Therefore, the first experi-
ment evaluated reaction concentrations
in detail.

Resin Preparation

Phenol-formaldehyde resins were pre-
pared in the laboratory at one of three
reaction concentrations: 43.0, 47.5,
or 52.0 percent by weight. Molar ratio
of sodium hydroxide to phenol was fixed
at 0.45, and molar ratio of formaldehyde
to phenol was 1.85. Each resin was
replicated three times. To prepare each
resin, all of the phenol, formaldehyde,
and water were placed in the reaction
kettle. The sodium hydroxide was added as
a catalyst at 20 ml every 10 minutes to
increase the pH gradually from 8.5 to
10.5. To initiate the reaction, the mix-
ture was quickly heated and maintained at
96-100°C (reflux temperature). When vis-
cosity reached Gardner-Holt viscosity C
(90 centipose), temperature was reduced
to 70°C. When viscosity reached Gardner-
Holt viscosity H (300 centipose), the
reaction was stopped by rapidly cooling
the mixture to 25°C.

Panel Preparation

All panels were prepared in the laboratory with flakes 3 inches long, 3/8 inch wide, and 0.015 inch thick. The flakes were from rotary-peeled veneer cut on a metal-working lathe and then clipped to width. Mixed hardwood flakes--50 percent red oak (Quercus falcata Michx.), 25 percent hickory (Carya sp.), and 25 percent sweetgum (Liquidambar styraciflua L.) --were dried to an average moisture content of 2 percent to 3 percent before adhesive was added. General conditions for panel preparation were:

Panel size--1/2 by 14 by 14 in.
Panel density--43.5 pcf
   (0.696 specific gravity)
Resin content--resin solids equaled
   5 percent of the ovendry weight of
   the wood furnish
Hot press temperature-335°F
Press closing time--45 s
Hot press time--4.5 or 7.5 min

Sampling and Testing

All boards were conditioned in a chamber controlled at 50 percent RH and 80°F until their moisture content averaged 5.9 percent. After conditioning, each board was cut into 2 - by 2-inch specimens for testing internal bond. Ten specimens were selected at random from each board. Internal bond tests were performed in accordance with ASTM standards for evaluating the properties of wood-base fiber and particle panel materials (ASTM D 1037-64.)(1)

Results and Discussion

As expected, internal bond (IB) was consistently higher with resins cured 7.5 minutes than with those cured 4.5 minutes (Fig. 1). With the shorter press time, the resin formulated at 47.5 percent concentration yielded the best IB; with the press time of 7.5 minutes, however, the resin formulated with 52 percent concentration gave the highest bond strength. Apparently the 52 percent resin requires slightly longer cure time to develop optimum strength than the 47.5 percent resin. Since fast cure time, not bond strength, was the primary objective of the study, the 47.5 percent reaction concentration was used for subsequent experiments.

Effects of Catalyst, Second Formaldehyde Addition, and Reaction Temperature

Procedure

To increase chemical reactivity more and to decrease cure time, three additional factors in resin formulation were considered: 1) effect of a second formaldehyde addition, 2) preparation of "high ortho" resin that cured rapidly by means of oxides or hydroxides of a bivalent metal ion such as calcium, and 3) effect of reaction temperature. Thus, the variables, in the experiment were:

1. Formaldehyde addition
   a. 1.8 mole at beginning
   b. 1.5 mole at beginning,
      mole after 2.5 hr of
      time.
2. Catalysts
   a. Sodium hydroxide
   b. Calcium hydroxide
3. Reaction Temperatures
   a. 95°C
   b. 75°C for first 2.5 hr
      increased to 95°C

Molar ratio of formaldehyde to phe
1.85, reaction concentration was 4
percent, and molar ratio of sodium
oxide to phenol was 0.45. Each re
replicated four times.

With both catalysts, reaction
adjusted initially to 8.5 and grad
increased to 10.5. However, becau
rapid loss of water solubility in
calcium resin, sodium hydroxide wa
after a reaction time of 1 hour.

Other details of resin prepar
board manufacture, and testing wer
described above. Differences amon
treatments were evaluated for stat
significance (P - 0.05) by analysi
variance.

Results and Discussion

Average IB values were subst
greater for resins cured 7.5 minut
for those cured 4.5 minutes (Table
There were no significant differen
IB among various resins cured 7.5
With the 4.5-minute cure time, how
timing of formaldehyde addition in
significantly with reaction temper
affect bond strength. At high rea
temperature, IB strengths of resin
second formaldehyde addition avera
nificantly higher (80 psi) than st
of resins with one-step addition o
formaldehyde (69 psi). At low rea
temperatures, however, IB was slig
greater for resins made with the o
addition of all formaldehyde (70 p
with the two-step addition (68 psi

No significant differences in
strength between resin catalyzed wi
monovalent sodium and bivalent cal
ions was detected. Although a cal
hydroxide catalyst reportedly resu
formation of "high ortho" thermopl
phenolic resin with a fast-cure ra
the calcium catalyzed thermoset ph
resin reported here offered no sig
improvement on IB as compared with
sodium catalyzed system at the sho
time (4.5 minutes). Explanation o
apparently conflicting results pro
lies in differences between thermo
and thermoset phenolic resin in re
pH and molar ratio of formaldehyde
phenol. Moreover, calcium cataly
had shorter storage life than sodi
hydroxide catalyzed resin and lost

Table 1. — IB STRENGTH RELATED TO RESIN FORMULATION VARIABLES

atalyst	Reaction Temperature	Formaldehyde[1] Addition	IB
	°C		Psi
t pressed 4.5 min			
NaOH	95	All	72.6
		Second	80.6
	75-95	All	67.8
		Second	69.8
Ca(OH)$_2$/NaOH	95	All	65.4
		Second	79.4
	75-95	All	71.4
		Second	66.6
t pressed 7.5 min			
NaOH	95	All	107.6
		Second	114.4
	75-95	All	100.8
		Second	102.8
Ca(OH)$_2$/NaOH	95	All	94.2
		Second	108.2
	75-95	All	96.8
		Second	94.6

All" means all formaldehyde was added initially; "second" means 1.5 mole was

dded at the beginning and another 0.3 mole was added after 2.5 hr.

lubility rapidly, making reaction of
is resin difficult to control.

Of all resins catalyzed with sodium
droxide, those reacted at high tempera-
re with a second formaldehyde addition
elded highest bond strength. A typical
action schedule for this resin is
mmarized in Figure 2.

ffects of Resin Content, Mat Moisture
ntent, Hot Press Time, and Hot Press
mperature

The best resin developed in the
evious experiments was tested under
rious gluing conditions to determine
s suitability to a wide range of mill
erations.

Board manufacture and specimen
earation were as described above, except
the special gluing conditions, as will
specified. Resin performacne was
asured by IB, bending strength, and
iffness of the panel, according to ASTM
andards (D 1037-64) (1).

Resin Content

Resin contents evaluated were 2, 4, 6,
8, and 10 percent of ovendry weight of wood
furnish. All strengthproperties increased
substantially as resin content increased
from 2 to 8 percent; as resin content
increased from 8 to 10 percent, modulus of
rupture (MOR) and modulus of elasticity
(MOE) increased only slightly and IB
decreased (Fig. 3). The IB decreased
mainly because excess moisture, intro-
duced by the additional resin, resulted in
less than optimum gluing conditions.

The lowest resin content to yield
adequate bond strength was 4 percent. An
average IB of 31 psi at 2 percent resin
content was about half that called for by
U.S. Commercial Standard CS 236-664 for
2B1 and 2B2 boards (65 and 60 psi,
respectively).

Mat Moisture Content

Mat moisture contents examined in
the experiment were 10, 12, 14, and 16
percent. Moisture content was adjusted
by spraying water on the flakes as they
tumbled in a rotating laboratory blender.

IB and MOR decreased as mat moisture content increased (Fig. 4). This result is to be expected because high mat moisture contents enhance densification of board surfaces and improve MOE. On the other hand, high mat moisture content may lead to excessive resin penetration and to formation of excessive trapped steam during hot pressing; either condition weakens IB and MOR.

Small pockets of delamination were found in several of the panels manufactured at 16% mat moisture content. Since production panels are considerably larger than the laboratory panels tested-- and hence dissipate steam more slowly-- it is likely that the safe limit for mat moisture content is near 14%.

Hot Press Temperature

Hot press temperatures examined in the study were 325°, 365°, 405°, and 430°F. The resin seemed to cure best at a hot press temperature of 365°F, which yielded the highest IB; further increases in press temperature decreased IB (Figure 5). Both MOR and MOE increased as hot press temperature increased, with the exception of MOR at 325°F.

Hot Press Time

Hot press times evaluated were 3, 4, 5, 7, and 9 minutes. All properties (IB, MOR, and MOE) improved as press time increased (Figure 6). A hot press time of 3 minutes was less than the minimum needed to yield adequate bond strength of 70 psi.

Mill Run

To examine the applicability of the laboratory results to industrial flakeboard production, 1/2 in by 4- by 8-ft hardwood flakeboards were manufactured at a Westvaco flakeboard plant in Tyrone, Pennsylvania.

Methods

In the laboratory, 150 gallons of phenolic resin were cooked in a 15-gallon reactor. The resin was frozen and shipped to the Westvaco plant. Hardwood flakes produced by a Miller-Hofft flaker were provided by Westvaco. More than half the flakes were red maple (Acer rubrum L.); the rest were a mixture of white ash (Eraxinus americana L.), black cherry (Prunus serotina Ehrh.), and aspen (Populus grandidentata Michx.)

The plant was using a resin cont of 7 percent and a press time of 8 mi In view of the large amount of fines the flake furnish, I felt that the ex mental resin content should be 5 perc even though satisfactory panels were produced in the laboratory with 4 per Press time was 4.5 minutes.

In the first press load, six pan out of 20 delaminated. It was then decided to increase press time by 1/2 minute. Forty panels were successful produced in two separate press loads 5 minutes press time with resin conte of 5.2 percent (based on calculation a metering device). Thereafter, a pr load of 20 panels was manufactured at each of the following conditions:

Resin content	Press tim
%	min
5.2	5
5.2	8
6.3	5
6.3	8

All panels were trimmed to 4 by 8 fee and shipped back to the Pineville, Louisiana, laboratory for testing IB. In addition, a supply of the furnish used in making the 4- by 8-foot panel was also shipped to Pineville, where laboratory panels were made under sim conditions for comparison.

Results and Discussion

Average IB (average specific gra was 0.737) for the mill and laborator panels was as in Table 2.

Mill panels had 20 to 22 percent lower IB than laboratory panels. Poo blending (i.e., application of resin flakes) in the mill was probably the major factor in the decrease of bond strength; the poor blending was readi apparent in the mill panels (Fig. 7).

Average IB in the mill panels wa 70 psi when press time was 5 minutes resin content was 5.2 percent. The d indicated, however, that a slight inc in either resin content or hot press would yield a satisfactory bond.

Summary and Conclusions

Although a second addition of formaldehyde is not a common practic manufacturing standard phenolic resi it improves bonding quality of resin subjected to short cure times. The formulated with a second formaldehyd addition at reaction concentration o percent and reaction temperature of resulted in highest bond strength. resin yielded satisfactory bonds in laboratory boards made of high quali flakes of mixed hardwoods with (1) a resin content of 4 percent, (2) a mi

Table 2. AVERAGE IB FOR LABORATORY AND MILL PANELS AT TWO RESIN CONTENTS

| Resin Content | Internal Bond | | | |
| | Hot pressed 5 min | | Hot pressed 8 min | |
	Lab panel[1]	Mill panel[2]	Lab panel[1]	Mill panel[2]
%	----------------------------------Psi----------------------------------			
5.2	87	70	112	88
6.3	107	86	135	105

[1]Each value is the average of 100 specimens (i.e., 20 specimens per 4 by 8 panel and 5 panels per treatment).

[2]Each value is the average of 75 specimens (i.e., 15 specimens per panel and 5 panels per treatment.

hot press time of 4 minutes, 3) a maximum mat moisture content of 14 percent, and 4) a hot press temperature of 325° F.

Four- by 8-foot, mill-run panels had 20 to 22 percent less internal bond strength than smaller panels made in the laboratory. A slight increase in either cure time or resin content was therefore indicated for satisfactory bond under mill conditions.

Experiment 2. Bonding Properties of Flakeboards from Hardwoods Growing on Southern Pine Sites

The phenolic resin in Experiment 1 is intended for use in structural exterior flakeboard made from mixed hardwoods grown on southern pine sites. Performance of the resin as related to wood species was therefore an important consideration. In Experiment 2, nine hardwood species were selected on the basis of their abundance and wide range of properties. Oaks were given special attention, since they comprise nearly half the South's volume of pine-site hardwoods. The variables studied were:

1) Nine hardwood species	Hardwood volume on pine sites
	%
Sweetgum (Liquidambar styraciflua L.)	13
White oak (Quercus alba L.)	12
Hickory (Carya spp.)	9
Southern Red Oak (Quercus falcata Michx. var falcata)	8
Post oak (Quercus stellata Wangenh.)	7
Black tupelo (Nyssa sylvatica Marsh.)	6
Red maple (Acer rubrum L.)	4
Sweetbay (Magnolia virginiana L.)	1
White ash (Fraxinus americana L.)	1

2) Board specific gravity (basis of volume and weight at moisture equilibrium with an atmosphere of 80°F and 50 percent RH).
   a) 39.5 pcf, 0.633 grams/cubic centimeter (g/cc)
   b) 44.5 pcf -- 0.713 g/cc
   c) 49.5 pcf -- 0.793 g/cc

3) Four replications--The fabrication of 39.5 pcf panels was limited to the five low-density species: sweetgum, black tupelo, sweetbay, white ash, and red maple.

Panel fabrication and testing procedures were as in Experiment 1. Flakes were from rotary-cut veneer 0.015-inch thick clipped to 3-inch length and 3/8-inch width.

Average IB ranged from 51 psi for white oak at a board density of 0.702 g/cc to 385 psi for black tupelo at 0.782 (Table 3). Bond strength increased with panel density for all species except sweetbay.

As expected, IB for the four densest species (i.e., hickory and the oaks) was significantly lower than for the other species, even though the resin coverage was greater. At 44.5 pcf all four species yielded panels with IB values less than the target level of 70 psi. When panel density was increased to 49.5 pcf, however, satisfactory bond strength was obtained.

The effects of board and wood density on bonding strength may best be expressed by their relation to compactness in the panel. Because high-density flakes required higher panel density to attain the same compaction as low-density flakes, the ratio between board density and wood density (i.e., the compaction ratio) was computed (Table 3, column 4) and related to bonding strength.

Regression analysis showed that bonding strength increased proportionately with

compaction ratio (Fig. 8). To attain the targe IB of 70 psi, the corresponding minimum compaction ratio would be 1.012.

The results also indicate that acceptable bond strength of 60-65 psi can be obtained with the resin for all species, but the required panel density may differ substantially among species. This finding is to be expected since hardwoods vary widely in wood density.

Experiment 3. Development of a New Adhesive System

Experiment 2 showed that panels of dense speices compacted sufficiently to meet strength requirements were so heavy-in excess of 50 pcf--that transportation would be costly and on-site handling difficult. Thus, a series of studies were conducted to develop a phenolic alloy which would not only yield specification-grade flakeboard over a broad range of wood species and densities at an acceptable panel density, but would also tolerate high flake moisture content and temperature, high temperature and humidity in the working area, low resin application, and conditions conducive to pre-cure.

Formation of Phenolic Alloys

The commercially available poly-methylene polyphenol isocyanate with functionality of 2.7 and viscosity of 200 to 275 cps at 25°C was chosen to react with phenolic resin in situ to form a combined adhesive system. A series of five flakeboards each were fabricated according to the following adhesive blending processes:

(A-1) Applied polyisocyanate before the phenol-formaldehyde resin adhesive
(A-2) Applied polyisocyanate and phenol-formaldehyde resin adhesive simultaneously
(A-3) Applied phenol-formaldehyde resin adhesive before the polyisocyanate.

Both phenol-formaldehyde resin and polyisocyanate were applied by conventional air-atomizing nozzles in a rotating drum-type blender. The phenol-formaldehyde resin was 75 percent of the total amount of adhesive and the polyisocyanate constituted 25 percent.

All flakes were produced by a shaping-lathe headrig to average 3 inches long, 0.015-inch thick, and were of random width. The mixed hardwood flakes were 40 percent sweetgum (Liquidambar styraciflua L.) and 60 percent southern red oak (Quercus falcata Michx.).

The panel fabrication and testing were similar to that of Experiment 1. The general conditions for panel preparation were:

Panel density--46 pcf
Panel thickness--1/2 in.
Resin content--4%
Hot press temperature--300°
Hot press time--4.5 minutes

Average IB was as follows:

Test	Adhesive blending process
A-1	Polyisocyanate before phenolic
A-2	Polyisocyanate and phenolic simultaneously
A-3	Phenolic before poly-isocyanate

These results indicate tha proved adhesive system can be a applying minor components of po cyanate before the major compon phenolic resin on wood furnish reacting the combined adhesive to obtain an improved thermoset adhesive resin suitable for har flakeboard. The polyisocyanate readily with hydroxy groups or the surface of or among the woo to form strong adhesion. Subse a cross-linking reaction betwee cyanate and phenolic resin occu reinforce the properties of phe adhesive.

Effects of Polyisocyanate:Phen Ratio

Evidence of the superior of an adhesive system in which nate is applied before phenol resin led to a study to determ ratio of polyisocyanate to phe hyde resin.

The panel fabrication and as in earlier tests except the time was 5.5 minutes and total content was 5 percent.

Polyisocyanate:resin rati internal bond strengths were:

Test	Polyisocyanate: phenolic resin ratio	Int I B
B-1	0/100	72
B-2	10/90	99
B-3	20/80	152
B-4	30/70	192
B-5	40/60	208
B-6	50/50	216
B-7	60/40	173

I
-Application of polyisocyana
phenolic resin. Application
nate and phenolic simultaneou
Application of polyisocyanate
phenolic resin.

The superiority of applying polyiso-
cyanate before phenolic resin is again
apparent. Also, increasing the ratio of
polyisocyanate to phenolic resin up to
50/50 resulted in increased bond strength.

Effects of Flake Moisture Content

To measure the tolerance of applying
polyisocyanate before phenolic resin when
wood furnish has a high moisture content,
two test conditions were chosen. The
panels were prepared as previously des-
cribed, again using a hot press time of
5.5 minutes and resin content of 5 percent.

Test conditions and average internal
bond strengths of the panels were:

Test	Flake moisture content	Polyisocyanate: phenolic resin ratio	IB
	%	%	psi
1	4	0/100	72
2	4	10/90	104
3	4	30/70	169
4	4	50/50	208
5	11	0/100	0
6	11	10/90	72
7	11	30/70	135
8	11	50/50	174

Results again clearly demonstrate the
efficiency of applying polyisocyanate be-
fore phenolic resin. Flakes having 11 per-
cent moisture content were satisfactorily
bonded by applying as little as 10 percent
of polyisocyanate before the phenolic
resin. In the conventional phenolic resin
system, steam generated from flakes with
high moisture content causes panel delami-
nation during hot pressing.

Effects of Panel Density

The high wood density of hardwood
species such as oaks and hickory makes
fabrication of low density panels diffi-
cult. To measure the tolerance of the
new adhesive system to high-density
hardwood species, southern red oak was
made into panels.

Half the panels (D-1, D-3, and D-5)
were fabricated with conventional phenol-
formaldehyde resin adhesive without poly-
isocyanate; panels D-2, D-4, and D-6
were fabricated by applying polyisocyanate
before phenolic resin. Hot press time and
total resin content were again 5.5 minutes
and 5 percent. The panels were prepared
and tested as described previously.

Panel characteristics were:

Test	Panel density	Polyisocyanate: phenolic resin ratio	IB
	pcf	%	psi
D-1	41	0/100	21
D-2	41	20/80	84
D-3	45	0/100	44
D-4	45	20/80	124
D-5	49	0/100	92
D-6	49	20/80	116

The panels fabricated with initial
application of polyisocyanate had consis-
tently higher internal bonds. Satisfactory
panels were produced even at 41 pcf, which
was not possible with the conventional
phenolic resin.

Effects of Resin Content

In the manufacture of flakeboard
panels, resin content strongly affects
panel performance and manufacturing eco-
nomics. Resin is the most expensive item
in manufacturing cost. To measure the
efficiency of the new adhesive system,
resin content was varied in the series E
panels.

The E-1, E-3, and E-5 panels were
fabricated with conventional phenol-
formaldehyde resin adhesive without poly-
isocyanate; for E-2, E-4, and E-6 panels,
polyisocyanate was applied before phenolic
resin. The hot press time and panel
density were 5.5 minutes and 44 pcf. The
panels were prepared and tested as
described previously.

Resin content and internal bond
strengths were:

Test	Resin content	Polyisocyanate: phenolic resin ratio	IB
	%	%	psi
E-1	3	0/100	43
E-2	3	20/80	71
E-3	4	0/100	56
E-4	4	20/80	139
E-5	5	0/100	68
E-6	5	20/80	152

The superiority of the resin system con-
taining polyisocyanate is again apparent
for all resin content levels in the test.

These tests confirm that applying
polyisocyanate before phenolic resin is
superior to phenolic resin alone when used
at high flake moisture contents and low
resin content levels. Satisfactory flake-
boards were formed from high-density
species such as southern red oak at sig-
nificantly lower panel density than that
attainable with conventional phenolic
resin systems.

References

1. American Society for Testing and Materials. 1977. Standard methods of evaluating the properties of wood-base fiber and particle panel materials. ASTM Desig. D 1037-64. ASTM, Philadelphia, Pa.

2. Bender, H.L. 1954. Hardening speed of phenoplasts. Mod. Plastics. 31(7): 115-116, 118, 200.

3. Hse, Chung-Yun. 1972. Influence of resin formulation variables on bond quality of southern pine plywood. For. Prod. J. 22 (9):104-108.

4. U.S. Department of Commerce, National Bureau of Standards. 1966. Mat-formed wood particleboard. Commercial Standard CS 236-66. U.S. Dep. Comm., Washington, D.C.

Table 3. — BONDING PROPERTIES OF FLAKEBOARD

Species	Actual Board Density	Wood Density[1]	Compaction Ratio	Panel Moisture Content	IB[2]
	--------g/cc------			%	Psi
Sweetbay	0.633	0.481	1.3155	5.4	109
	.708		1.4715	7.2	260
	.738		1.5339	6.6	236
Red maple	.648	.538	1.2044	5.9	97
	.755		1.3988	5.0	284
	.788		1.4648	6.0	315
Sweetgum	.638	.547	1.1659	5.5	81
	.723		1.3213	5.8	171
	.793		1.4493	6.1	196
Black tupelo	.625	.518	1.2075	4.9	113
	.721		1.3920	4.8	239
	.783		1.5118	6.0	385
White ash	.633	.646	.9793	5.0	83
	.708		1.0954	5.2	148
	.800		1.2386	6.0	273
Red oak	.705	.667	1.0577	5.0	55
	.788		1.1815	6.6	146
Hickory	.708	.702	1.0079	5.0	65
	.810		1.1539	6.3	107
Post oak	.703	.733	.9584	7.0	58
	.790		1.0779	6.8	119
White oak	.702	.762	.9211	6.9	51
	.795		1.0428	5.8	88

[1] Volume and weight at equilibrium in atmosphere held at 80°F and 50 percent RH. Nominal values for the three board densities were 0.633, 0.713, and 0.793.

[2] Each value is the average of 20 observations.
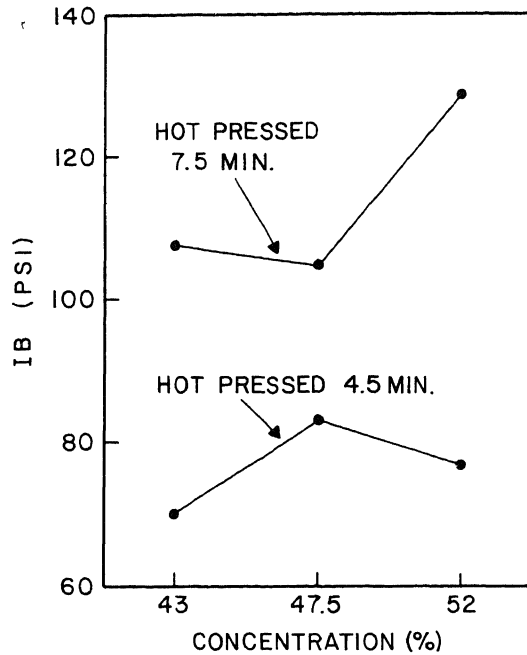
Figure 1.-- Relationship of reaction concentration to IB strength
of mixed-species boards made from lathe flakes (with
Hse's "Fast-cure Phenolic Resin"(1)).
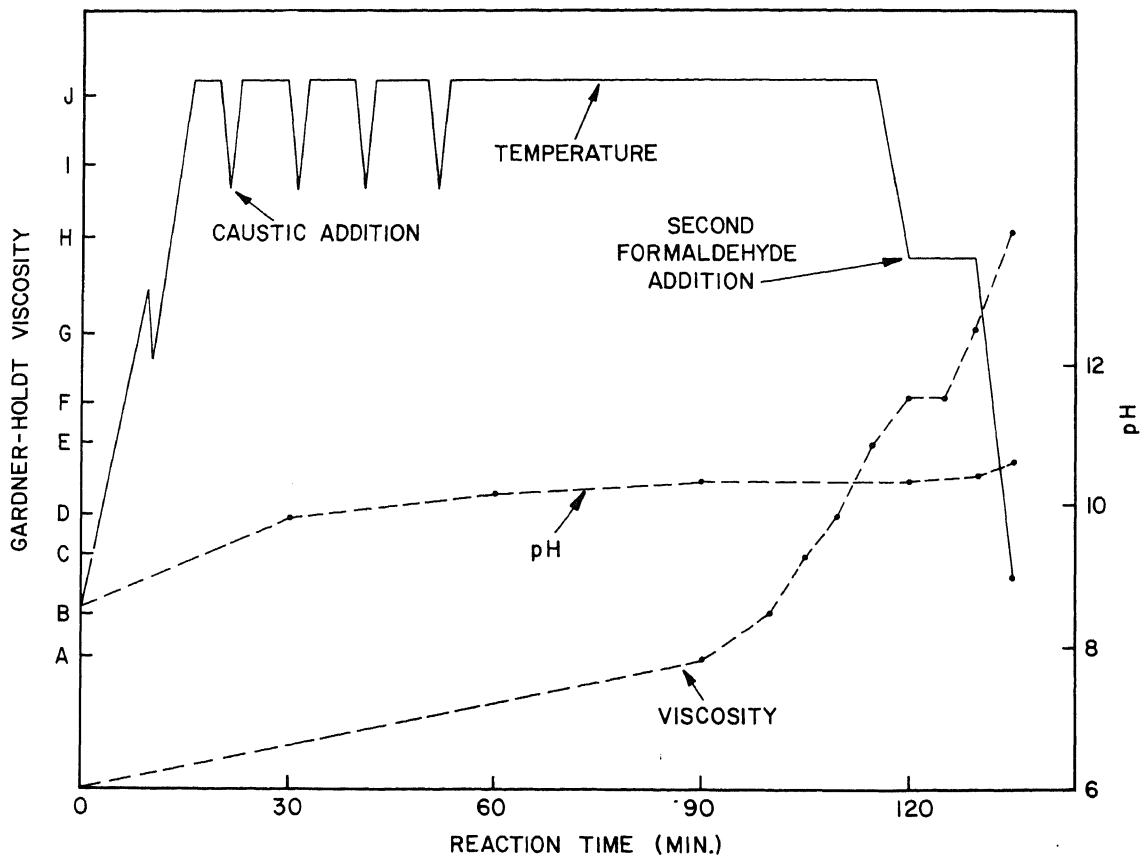
Figure 2.-- Viscosity, pH, and reaction temperature as related
to reaction time (with Hse's "Fast-Cure Phenolic
Resin" (1)).
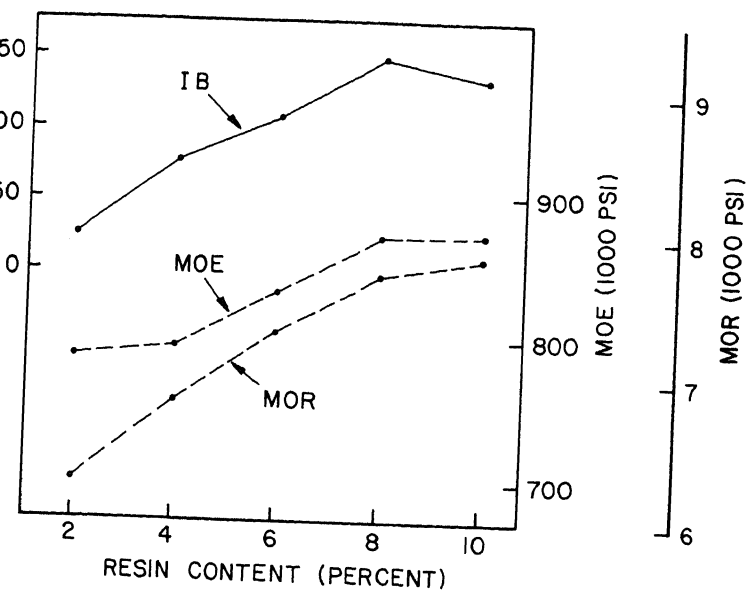
Figure 3.-Effect of resin content on IB, MOR, and MOE (with Hse's "Fast-cure Phenolic Resin" (1)).

RESIN CONTENT (PERCENT)
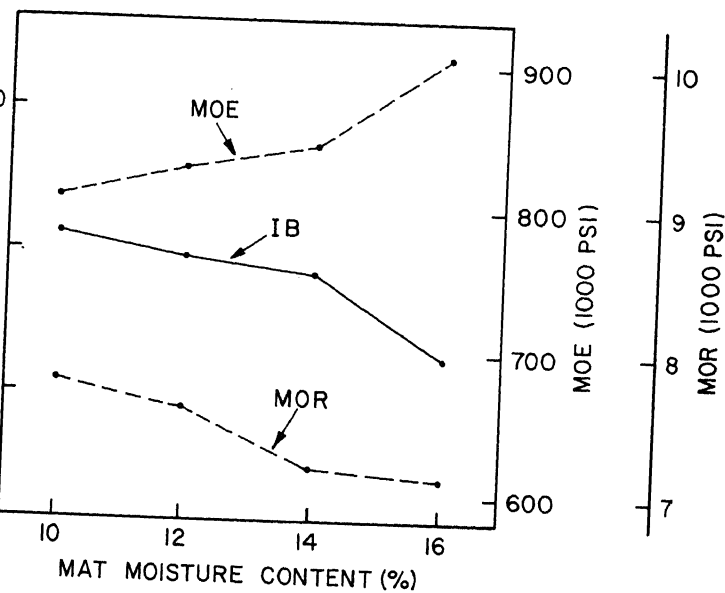
Figure 4.-Effect of mat moisture on IB, MOR, and MOE (with Hse's "Fast-Cure Phenolic Resin"(1)).

MAT MOISTURE CONTENT (%)
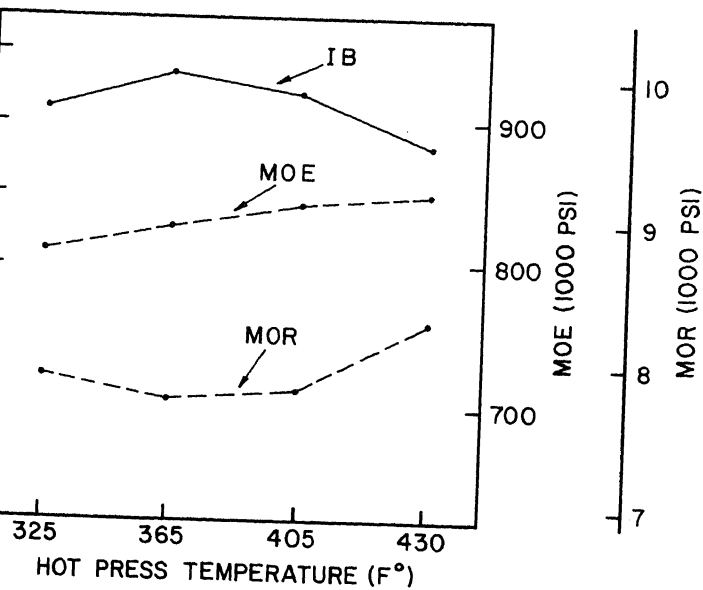
Figure 5.-Effect of hot press temperature on IB, MOR, and MOE (with Hse's "Fast-Cure Phenolic Resin"(1)).

HOT PRESS TEMPERATURE (F°)
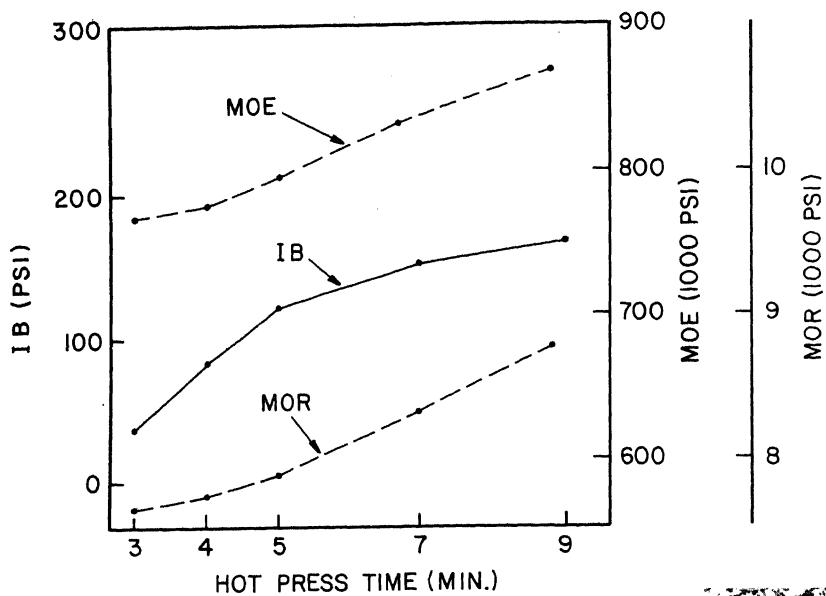
Figure 6.--Effect of hot
on IB, MOR, and MOE (wit
"Fast-Cure Phenolic Resi

Figure 7.--Mixed species hardwood flakeboard made in
the laboratory (left) and in the mill (right) with
Hse's "Fast-Cure Phenolic Resin" (1).

$Y = -358 + 423X$
$r = 0.85$
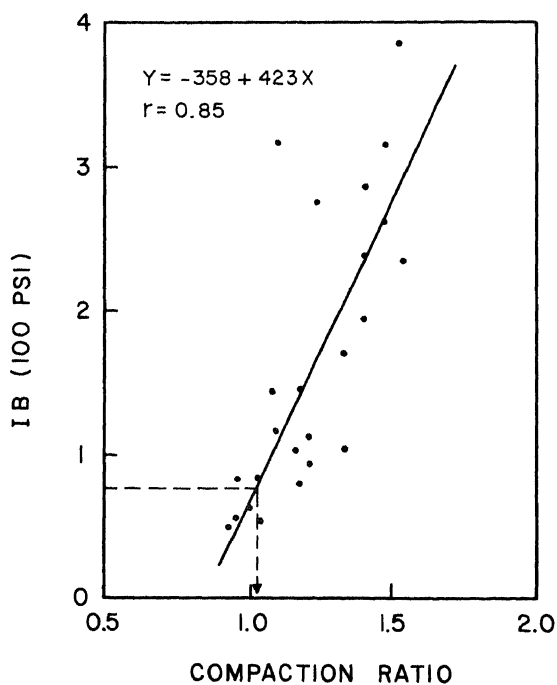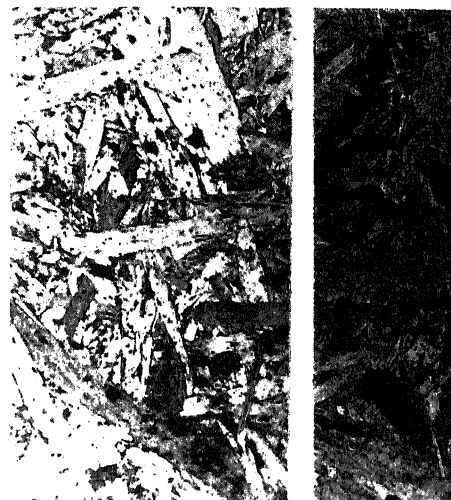
Figure 8.--Relationship of compaction ratio to I
Dashed lines indicate the compaction ratio corre
sponding to an attainable average of 70 psi IB.

ACCELERATED AGING OF PHENOLIC-BONDED FLAKEBOARDS

Andrew J. Baker
Chemical Engineer
Forest Products Laboratory
USDA Forest Service
Madison, Wisconsin

Robert H. Gillespie
Chemist
Forest Products Laboratory
USDA Forest Service
Madison, Wisconsin

Abstract

Specimens of phenolic-bonded flakeboard, vertical-grain southern pine and Douglas-fir, and marine-grade Douglas-fir plywood were exposed to four accelerated aging situations. These consisted of: 1) Multiple cycles of boiling and elevated-temperature drying, 2) multiple cycles of vacuum-pressure soaking and intermediate-temperature drying, 3) the six-cycle ASTM D-1037 exposure and, 4) continuous exposure to weathering at the Madison, Wis. site. Thickness change and bending strength, bending stiffness, and internal bond strength retention were measured after various numbers of exposure cycles, or time of exposure. The phenolic-bonded flakeboards retained enough strength and stiffness during accelerated aging to indicate they might be used satisfactorily in structural applications where conventional wood products are now used.

Introduction

The acceptance of new types of structural grades of flakeboard would be stimulated if suitable long-term service life can be demonstrated. The purpose of this study was to develop methods for assessing such service life and to apply these methods to evaluate selected prototypes of flakeboard from forest residues. This work was to determine the life-expectancy of phenolic-bonded flakeboard using accelerated aging by comparing its response with that of exterior-type plywood and of solid lumber.

There is much misunderstanding about accelerated-aging tests--the experimental techniques, analysis, interpretation of results, correlations, and objectives. But accelerated-aging tests are an essential step in the process of developing new products for use in critical, long-term applications. They can provide insight into degradation that could occur in service and thereby reduce the risk that an inadequate product might appear in the marketplace.

Evaluating a phenolic-bonded flakeboard for long-term performance is a different problem from that of evaluating a new adhesive system for its potential use in wood products. Structural flakeboard is made with an adhesive known to have excellent resistance to thermal degradation, to hydrolysis by moisture, and to the swelling and shrinking stresses a variety of acceptable wood products impose on the gluelines. These facts were responsible for selecting phenolics as the binder system in structural grades of flakeboard. The problem then, was to devise accelerated-aging tests to evaluate a bonded wood product for the retention of properties that are important in the intended end use.

The principal intended end use for structural flakeboard is for wall, roof, and floor sheathing where bending strength and stiffness are the important properties governing design and application. Because of this, bending strength and bending stiffness were the primary properties evaluated.

The intended end use also requires the product to resist the changing moisture conditions that arise in service. Because of this, phenolic-bonded flakeboard will be considered under requirements similar to those of exterior-type softwood plywood and not of the intermediate or interior types that are often used for sheathing purposes.

Background Review

Cyclic boil-dry treatments are most often used for evaluating weather-resistant products. This treatment maximizes the effect of three important influences that cause degradation--heat, moisture, and swelling and shrinking stresses. Boil-dry cycles are an empirical mixture of the three influences rather than any logical or intended simulation of a real-life situation. But repeated boil cycles have the potential to degrade weather-resistant products in the laboratory at a relatively rapid rate so that comparison between products can be made in a short time.

The accelerated-aging procedures in common use today for evaluating wood-based materials were developed primarily for quality-control purposes. In fact, ASTM D 1037 cyclic test for accelerated aging (1), which is a mixture of soaking, steaming, freezing, and drying through 6 cycles requiring 12 days, is the prescribed test in the product standard for Type 2 mat-formed wood particleboard (CS 236-66) (12). The West Coast Adhesive Manufacturers Association (WCAMA) (15,16) attempted to reduce the time required for this test by a 6-cycle procedure of vacuum-pressure soaking, boiling, and

drying to be completed in 6 days. This exposure and the D 1037 treatment are much more complicated and time-consuming than the single boil-dry-boil used for quality control in the manufacture of interior-type softwood plywood (PS-1-74) (13).

Shen and Wrangham (11) more recently reported on the development of a rapid accelerated-aging test also for quality-control purposes. They evaluated the 2-hour boil followed by wet testing, described in the German Standard DIN 68761 (5) for change in internal bond (IB) strength. This exposure was used in the Canadian Standard (CSA 0188-68) (3) but applied to bending specimens. Shen and Wrangham then correlated torsion shear testing with the more traditional IB test. But any of these quality-control tests provide only limited information-- a two-point, before-and-after condition. They cannot be used for estimating the long-term performance.

There is little background information about how particleboard responds to exterior exposure--none of it extends for longer than 8 years. The WCAMA tests with board of unknown particle geometry showed MOR losses of over 50 percent in 5 years. The most extensive information on flakeboard durability was that by Hann, Black, and Blomquist (7,8) and Jokerst (9) at the Forest Products Laboratory. Weathering of phenolic-bonded flakeboards showed bending strength losses of 50 to 63 percent in 8 years at the Madison site. Clad and Schmidt-Hellerau (4) reported data for 3-year exposures on particleboards produced in Germany with alkaline-type phenolic adhesives. All of this work shows a general pattern of rapid loss of strength and stiffness during the first year or two of exposure with a much slower rate of loss in subsequent years, at least through 8 years.

Repeated boil-dry cycles to follow strength losses throughout a product's useful life are difficult to perform in the laboratory. A limited attempt to do this was made during the early development of the rate-process method of analysis (6). Specimens were carried through as many as 35 standard boil-dry-boil cycles (PS-1-74), but this was time-consuming and difficult to carry out manually during normal working hours. Attempts to develop machines to carry out cyclic tests automatically have been described in the literature from time to time with the most successful initiated at the Canadian Forest Products Laboratory in Vancouver (14). This equipment was further refined and extensively evaluated by the Weyerhaeuser Company (10). The developed method has been adopted as an ASTM Standard (D 3434, Multiple-Cycle Accelerated-Aging Test (Automatic Boil Test) for Exterior Wet-

Use Wood Adhesives) (2). While the equipment was designed and used for evaluating standard plywood shear specimens, small lap specimens, and finger-joint specimens, modifications in design would adapt the unit to evaluate larger sized specimens such as flakeboard bending specimens. Any extended program of research involving cyclic accelerated aging of either products or adhesives would benefit from a machine of the Weyerhaeuser type.

Experimental Procedures

Materials

Flakeboard, plywood, and wood samples were selected for comparison. Each was assigned an alphabet identification that is referred to in the Results and Discussion and all tables and figures. These materials are described in Table.

Specimen Selection

Each material was cut into specimens 1/2 by 2 by 12 inches. Enough specimens were cut to carry out the planned treatments and sampling schedules. All specimens were conditioned to 80°F (65 percent relative humidity (RH)) prior to and after accelerated-aging exposures to achieve comparable moisture conditions at time of test. Specimens were mounted on racks designed to maintain a 1/4-inch space between them during the aging treatments.

Accelerated-Aging Exposures

Boil-dry exposure

Thirty specimens from each material were saturated with water by vacuum-pressure soaking and immediately placed in boiling water. There was sufficient stored heat to maintain boiling conditions when cold wood samples were placed in the bath. Distilled water was used in the bath to reduce scaling problems. After 10 minutes, the specimens were removed, allowed to drain momentarily, and then placed in an air circulating oven at 225°F for drying. At the end of 3-3/4 hours, the specimens were removed and weighed. The drying time was selected so that moisture content of the slowest drying material was reduced to 6 to 8 percent.

The vacuum-pressure soak was applied only before the first boiling treatment and not applied to subsequent cycles. Five randomly selected specimens were removed from each set for test after each of the prescribed cycles--1, 5, 10, 20, 40, and 80. Two cycles per day could be accomplished.

Vacuum-pressure-soak-dry exposure

Replicates of five specimens for each material were subjected to 1, 5, 10, 20, and 40 cycles of vacuum-pressure-soak-dry cycles. Each cycle consisted of 30

minutes at 29 inches Hg vacuum and 30 minutes of pressure at 60 psi submerged in tap water and 23 hours of drying in a forced-draft oven at 180°F. Weighing specimen sets before and after cycling assured that the slowest drying material was reduced to 6 to 8 percent moisture content during drying. One cycle per day could be accomplished.

Accelerated aging by ASTM D 1037

Five specimens for each material were subjected to accelerated aging by ASTM D 1037 accelerated-aging test procedures consisting of 6 cycles of the following sequence:

1. Soaking in water at 120°±3°F--1 hour.

2. Spraying with steam and water vapor at 200°±5°F--3 hours.

3. Storing at 10°±5°F--20 hours.

4. Drying at 210°±3°F--3 hours.

5. Repeating 2 above--3 hours.

6. Repeating 4 above--18 hours.

This procedure requires a minimum of 12 days and was carried on for each material, yielding only before and after values.

Outdoor exposure

Thirty individual specimens from each material were placed on an exposure rack at the Madison site. The specimens were attached with brass screws and exposed at an angle of 60° to the horizontal facing south. At various intervals of time, five randomly selected specimens from each set are planned for removal for test. After the first year of exposure, subsequent exposure periods will depend upon the extent of degradation each material already experienced, with the view to test all specimens of each type while specimen integrity is still maintained and reasonable rates of property loss can be measured.

Measurements and Physical Testing

Specimens were measured for thickness and width after conditioning at 80°F, 65 percent RH. The weight of specimen sets was measured before and after accelerated aging exposure and after conditioning. conditioning at 80°F, 65 percent RH.

Each specimen was tested for bending strength, bending stiffness,[1] internal

_____

[1] The terms "bending strength" and "bending stiffness" are used because the specimens used in this study are smaller than the specimen specified in ASTM D 1037 (3 by 14 in.) for determination of modulus of rupture and modulus of elasticity of 1/2-inch-thick specimens.

bond strength, and thickness swell. A span of 10 inches was used in the bending measurements.

Measurements of tensile strength perpendicular to the face (internal bond) were carried out on the ends of the specimens broken in the bending strength tests, selecting portions that received the least strain during bending.

Data Analysis

Bending strength and bending stiffness were calculated on the basis of original dimensions measured at 80°F, 65% RH, before exposure to accelerated aging. For unexposed materials, the mean and standard deviation were calculated for the replicates tested to provide an original property value and an indication of the variability in the unexposed materials. The mean value for replicates of exposed specimens was calculated and converted to a percentage of the property retained by comparison with the original mean value. Any change in variability that might have taken place during aging was found not to influence the general conclusions reached in this study.

The percentage change in each property obtained during accelerated aging was plotted against the number of cycles exposed. Inspection of a large number of these plots revealed a rapid property loss in the first cycle followed by a generally uniform slower rate of loss in subsequent cycles. Consequently, a linear regression line was calculated by the least squares method to provide an average rate of change of all specimens of each material subjected to accelerated aging. The values for unexposed specimens was not included in the calculations of the regression lines. Because of the limited number of replicates, the variability among specimens, and the limited objectives of this study, more sophisticated analysis of the data was unwarranted.

Results and Discussion

The properties of the unexposed materials evaluated are given in Table 2. The flakeboards at 0.60 to 0.64 specific gravity were generally more dense than plywood and solid wood at 0.47 to 0.50 specific gravity. Flakeboard bending strength ranged from about 2,658 psi to 4,927 psi, in contrast with plywood at 6,663 psi, Douglas-fir lumber at 14,346 psi, and southern pine lumber at 16,176 psi. Bending stiffness for the flakeboards was between 508,000 and 677,000 psi; plywood, 965,000 psi; Douglas-fir wood, 2,007,000 psi; and southern pine, 1,990,000 psi. The internal bond value of 127 psi for plywood was within the range of the values of 69 to 164 psi for the flakeboards, as compared with the much higher values of 372 psi for Douglas-fir wood and 612 psi for southern pine wood.

The results of the accelerated-aging tests are shown in Figure 1 for bending strength response, in Figure 2 for bending stiffness, in Figure 3 for internal bond strength, and in Figure 4 for changes in thickness swelling. The figures include regression lines for each material subjected to the cyclic boil-dry and vacuum-pressure soak-dry treatments, each marked with the appropriate letter code. The results of the D 1037 test and the 1-year test fence exposure, providing single values for each material, are shown in the figures on a separate "percent retained" axis with the individual letter codes placed at the point of retention obtained.

With regard to bending strength, Figure 1, all accelerated-aging tests appeared to differentiate among the materials in the same way. The highest bending strength retention was obtained with solid wood and plywood. The four laboratory-prepared flakeboards were similar in their bending strength retention, which was generally at somewhat lower level than solid wood and plywood. The lowest bending strength retention was shown by the commercially prepared waferboard, but it still retained 30 to 40 percent of its strength after the D 1037 test and after 40 cycles of vacuum-pressure-soak-dry or 50 cycles of the boil-dry test. The commercially prepared waferboard is believed to have a lower binder content than the laboratory-prepared flakeboards evaluated here. One year of test fence exposure reduced bending strength no more than 25 percent in all cases. For the flakeboards, 10 boil-dry cycles reduced strength more than 1 year on the test fence, while 10 cycles of the vacuum-pressure-soak dry treatment reduced strength less than 1 year on the test fence.

The bending stiffness (Figure 2) of solid wood and plywood did not change appreciably during any of the accelerated-aging treatments. Stiffness appeared to increase slightly during the cyclic wetting and drying treatments with the lumber and plywood, and only 10 percent or less was lost by the D 1037 test or 1-year test fence exposure. The four laboratory-prepared flakeboards lost stiffness with wet-dry cycling but still retained 70 to 80 percent after 80 boil-dry cycles or 80 to 90 percent after 40 VPS-dry cycles. The D 1037 test and 1 year of test fence exposure produced bending stiffness losses about equivalent to those caused by 50 to 60 boil-dry cycles and 40 VPS-dry cycles. Again, the commercially prepared waferboard lost bending stiffness to a greater extent than did the other materials evaluated, but still retained more than 40 percent under the most severe treatment, 80 boil-dry cycles.

The internal bond strength (Figure 3) was the strength property undergoing the most change during accelerated aging. Even the D 1037 test produced a 20 percent loss in internal bond with solid wood and plywood. This loss was equivalent to the loss after 10 to 20 boil-dry and VPS-dry cycles. Continued cycling produced drastic reductions in internal bond strength with all materials evaluated, with the greatest loss being exhibited by the commercially prepared waferboard. One-year exposure on the test fence produced only moderate losses of internal bond strength with the flakeboards (60 percent or better retention) and little change in Douglas-fir and plywood.

The southern pine lumber, after exposure to the D 1037 conditions, yielded lower internal bond strength than expected. Southern pine lumber became noticeably checked in all accelerated tests and posed experimental problems during testing, especially in internal bond strength measurements.

There appeared to be some differences among the four laboratory-prepared flakeboards with regard to internal bond retention, variances which were not differentiated by either bending strength or stiffness measurements. The residue flakeboard B lost internal bond strength to a greater extent than did flakeboard A which had been prepared with a higher binder content. Flakeboard L, similar to flakeboard B but prepared from a different residue mix, lost internal bond strength at a rate intermediate to that exhibited by flakeboards A and B. The removal of fines from flakes to produce flakeboard O appeared to have little effect on internal bond retention in either the boil-dry cycles or the D 1037 test. There was a hint of improvement caused by fines removal with the VPS-dry treatment, but it is highly unlikely that the noted difference is statistically significant considering the variability in the data.

As expected, there was little residual thickness swelling (Figure 4) with the two solid wood samples or plywood in any of the accelerated-aging treatments. Of these, the 4 percent thickness swelling of plywood was the greatest. All laboratory-prepared flakeboards exhibited thickness swelling ranging from about 14 percent to 27 percent, and the commercially prepared waferboard swelled over 40 percent after 80 boil-dry cycles. The boil-dry cycles caused most of the thickness swelling during the first few cycles, with only minimal changes thereafter. The VPS-dry cycles caused less swelling during the first few cycles. The swelling gradually increased to about the same swelling after 40 VPS-dry cycles that was obtained after 1 to 5 cycles of the boil-dry treatment. The D 1037 produced about the same thickness swelling as 1 to 5 boil dry cycles or 40 VPS-dry cycles, with the exception of the waferboard.

Thickness swelling after 1-year test fence exposure was no greater than 10 percent, in all cases.

The test fence exposures were considered to be an accelerated treatment because individual test specimens, rather than panels were exposed in a position to provide maximum opportunity for wetting and drying. After 1-year exposure, two laboratory-prepared flakeboards (A and B) retained 83 and 91 percent bending strength and 90 and 71 percent internal bond strength, respectively. Previous outdoor exposure tests (7,8,9) had involved panel exposure in a vertical position facing south and strength test specimens were cut from panel centers with the edges discarded--a much less rugged exposure. A flakeboard bonded with 6 percent phenolic resin and no wax, when exposed in this fashion for 1 year, retained 52 percent bending strength and 47 percent internal bond strength. After 8 years' exposure these values decreased only to 48 percent bending strength retention and 33 percent internal bond strength retention. Comparing these results with those from the present study where fence exposure degradation was accelerated suggests that the phenolic-bonded flakeboards should perform well for many years during outdoor weathering. Results of strength tests after additional years of exposure will be needed to verify this indication.

Significance of This Work

The results of these accelerated-aging tests, provide confidence that phenolic-bonded flakeboards manufactured from forest residues would serve well in many structural applications. They retained a respectable level of bending strength and stiffness when exposed to soaking and drying so severe that even solid lumber and marine-grade plywood, whose performance is well recognized, suffered appreciable losses.

A comparison of the accelerated aging procedures suggests that multiple cycles of boiling and drying, capable of automation, could detect differences in material behavior in a manner similar to that produced by the standard, but more complicated, method.

References

1. American Society for Testing and Materials. 1977. Standard methods of evaluating the properties of wood-base fiber and particle panel materials. ASTM Desig D 1037-72. ASTM, Philadelphia, Pa.

2. American Society for Testing and Materials. 1977. Standard recommended practice for multiple-cycle accelerated aging test (automatic boil test) for exterior wet-use wood adhesives. ASTM Desig D 3434-75.

ASTM, Philadelphia, Pa.

3. Canadian Standards Association. 1975. Mat-formed wood particleboard. CSA-0188-1975. CSA Rexdale, Ontario.

4. Clad, W., and C. Schmidt-Hellerau. 1965. Behavior of amino plastic and phenolic resins in particleboard during outdoor exposure. Hold-Zentralblatt 44/45:349-352.

5. German Standard. 1973. Particleboards; flat-pressed boards for building; terms, properties, testing, supervision. DIN 68763. Deutsche Normenausschusses, Berlin.

6. Gillespie, R.H. 1965. Accelerated aging of adhesives in plywood-type joints. For. Prod. J. 15(9):369-378.

7. Hann, R.A., J.M. Black, and R.F. Blomquist. 1962 How durable is particleboard? For. Prod. J. 12(12):577-584.

8. Hann, R.A., J.M. Black, and R.F. Blomquist. 1963. How durable is particleboard: Part II. The effect of temperature and humidity. For. Prod. J. 13(5):169-174

9. Jokerst, R.W. 1968. Long-term durability of laboratory-made Douglas-fir flakeboard. USDA For. Serv. Res. Note FPL-0199. For. Prod. Lab., Madison, Wis.

10. Kreibich, R.E., and H.G. Freeman. 1968. Development and design of an accelerated boil machine. For. Prod. J. 18(12):24-26

11. Shen, K.C., and B. Wrangham. 1971. A rapid accelerated-aging test procedure for phenolic particleboard. For. Prod. J. 21(5):30-33.

12. U.S. Department of Commerce, National Bureau of Standards. 1966. Mat-formed wood particleboard. Commercial Standard CS 236-66. U.S. Dept. Comm. Washington, D.C.

13. U. S. Department of Commerce, National Bureau of Standards. 1974. Construction and industrial plywood. Voluntary Product Standard PS-1-74. U.S. Dept Comm. Washington, D.C.

14. Walser, D.C., and H.G.M. Colbeck. 1967. Bond-degrade accelerating machine helps predict bond life. Adhesives Age 10(11):33-35.

15. West Coast Adhesive Manufacturers Association Technical Committee. 1966. A proposed new test for accelerated aging of phenolic resin-bonded particleboard. For. Prod. J. 16(6):19-23.

16. West Coast Adhesive Manufacturers Association Technical Committee. 1970. Accelerated aging of phenolic-resin bonded particleboard. For. Prod. J. 20(10):26-27.

Table 1.--DESCRIPTION OF 1/2-INCH BOARD MATERIALS.

						Press Conditions	
Material	Species	Flake	Board Weight	Phenolic Resin	Wax	Press Temperature	Time to Thickness
		In.	Pcf	%	%	°F	Min
A FPL flakeboard	Douglas-fir	0.015 x 1 random width	40	6	1	350	1
B FPL residue mix (15-70-15 weight)	Douglas-fir	faces 0.02 x 1 x 2 disk core 0.05 x 2 random width ring	40	5	1	350	1
C Commercial waferboard	Aspen				Yes		
L FPL residue mix (15-70-15)	Douglas-fir	faces 0.02 x 1 x 2 disk core 0.05 x 2 random width ring	44	5	1	350	1
O FPL residue mix (15-70-15) fines removed	Douglas-fir	faces 0.02 x 1 x 2 disk core 0.05 x 2 random width ring	41	5	1	350	1
P Commercial plywood	Douglas-fir				Yes		
W Heartwood	Douglas-fir						
X Sapwood	Southern pine						

Table 2.-- PROPERTIES OF UNEXPOSED MATERIALS.

Material	Specific Gravity	Thickness	Bending Strength[1]	Bending Stiffness[1]	Internal Bond[1]
		In.	Psi	Thousand psi	Psi
A FPL flake	0.64	0.51	4,927 (760)	677 (70)	164 (20)
B FPL residue flake	.61	.52	3,799 (650)	608 (57)	83 (21)
C Commercial wafer	.60	.53	2,658 (335)	508 (34)	69 (12)
L FPL residue flake	.63	.52	4,588 (1,117)	711 (104)	107 (16)
O FPL residue flake	.62	.52	4,886 (667)	670 (26)	125 (21)
P Plywood	.47	.48	6,663 (915)	965 (180)	127 (24)
W DF wood	.48	.50	14,346 (1,900)	2,007 (276)	372 (66)
X SP wood	.52	.50	16,176 (1,937)	1,990 (366)	612 (89)

[1]First value is mean for 10 specimens tested for materials A, B, C, P, W, and X, and for 5 specimens for L and O. Value in parentheses is standard deviation.
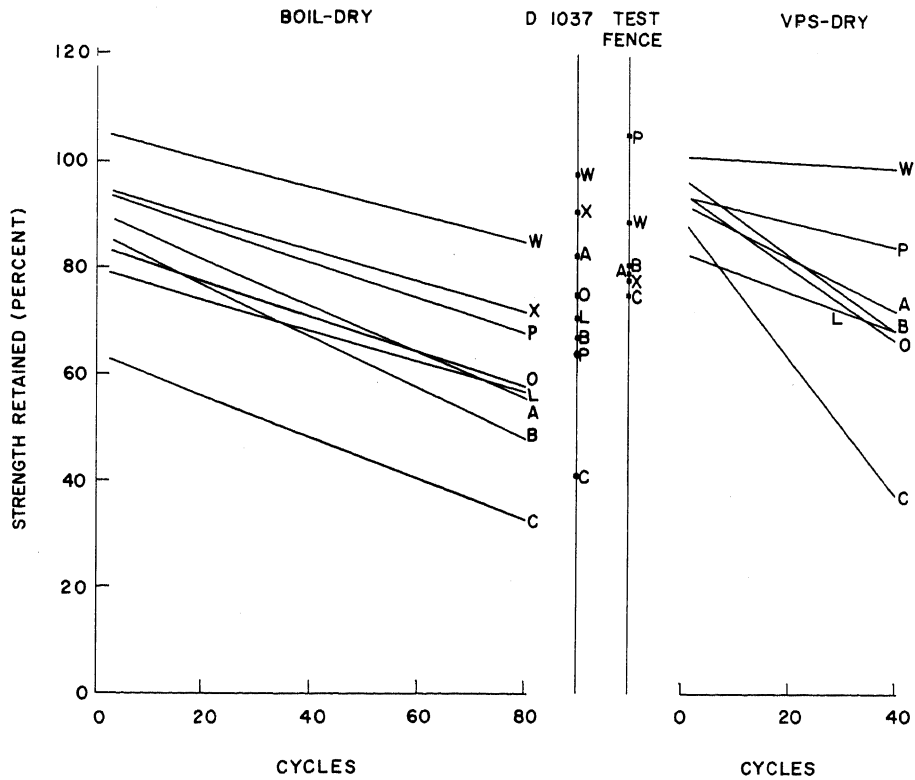
Figure 1.--Bending strength of material. A, B, C, L, and O are flakeboards
    P is plywood, and W, X are from solid wood (see Table 1 for identification).
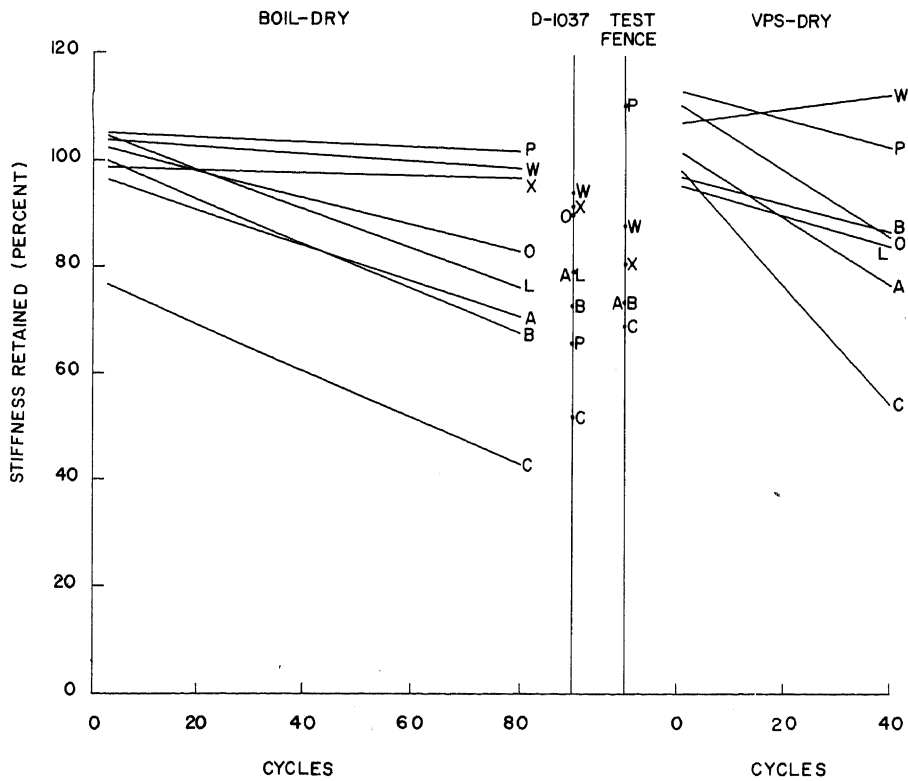
Figure 2.--Bending stiffness of material. A, B, C, L, and O are flakeboards,
    P is plywood, and W, X are from solid wood.
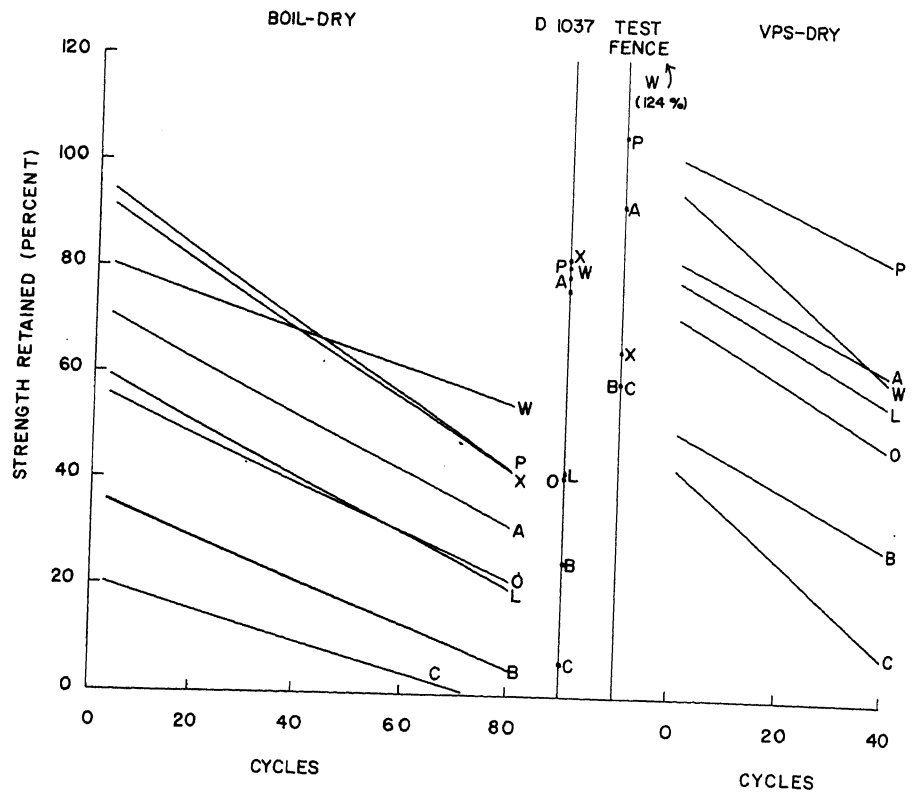
Figure 3.--Internal bond of materials. A, B, C, L, and O are flakeboar
P is plywood, and W, X are from solid wood.
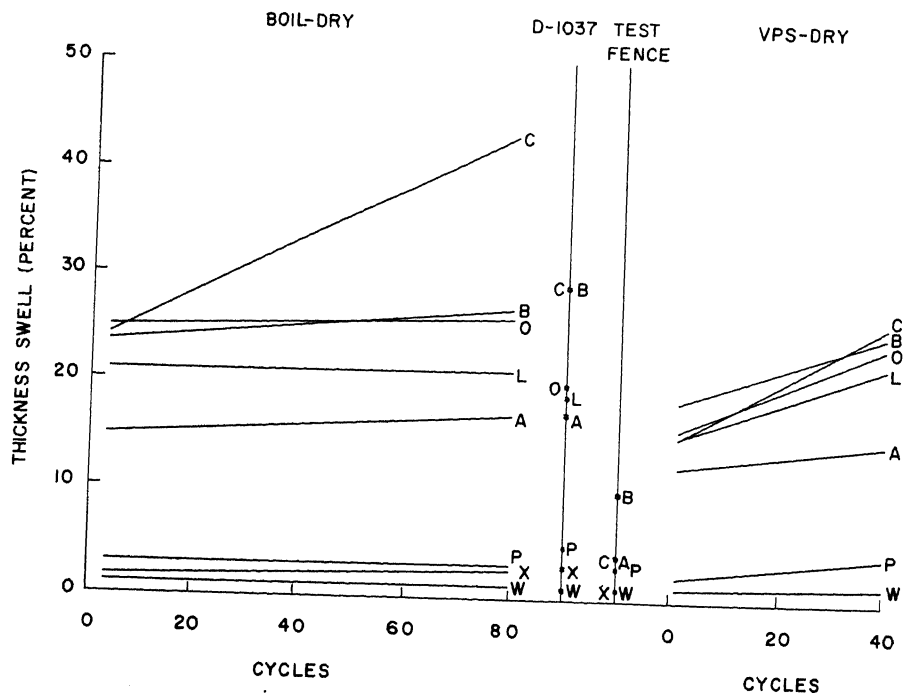
Figure 4.--Thickness swell of material. A, B, C, L, and O are flakeboar
P is plywood, and W, X are from solid wood.

PROPERTIES OF FLAKEBOARD PANELS MADE FROM SOUTHERN SPECIES

Eddie W. Price[1]
Wood Scientist
Southern Forest Experiment Station
USDA Forest Service
New Orleans, Louisiana

Abstract

Structural exterior flakeboards manufactured with phenolic resin and flakes produced on a shaping-lathe headrig were evaluated for plate shear modulus, internal bond, bending properties, uniform loading, concentrated loading, and impact resistance. Both mixed- and single-species 4- by 8-foot flakeboards were produced. Panels with mixed flakes had 20 percent by weight of hickory, white oak, southern red oak, sweetgum, and southern pine. The variables in fabricating these panels were:

1) Aligned (oriented face and core flakes in panels of two densities and thicknesses of 1/2 and 5/8 inch.

2) Randomly oriented (random) face and core flakes in panels of two densities and thicknesses of 1/2 and 5/8 inch.

Single-species, 1/2-inch-thick boards of one density class were fabricated with random flakes of yellow-poplar and loblolly pine.

Regression equations for the mixed species panels indicated that at 45 pcf density, a shear modulus of 192,000 psi would be obtained for the oriented panels. Random panels of this density would have 35 percent larger shear modulus. Based on a specimen's initial dimensions, 70 percent of the bending strength was retained, while the modulus of elasticity increased after accelerated aging exposure. Initial bending properties depended on panel direction tested and on flake orientation. Oriented panels stressed along the 8-foot axis had the highest bending strength (5,412 psi for 1/2-inch panels); bending strength across the 4-foot width was lower (3,346 psi). Modulus of elasticity was more affected by flake alignment than was bending strength. In oriented panels modulus of elasticity was 967,000 psi along the 8-foot axis and 377,400 psi across the panel; random panels stressed along the 8- and 4-foot axes had bending strengths of 5,034 psi and 4,214 psi and moduli of elasticity of 710,400 psi. When bending strength and modulus of elasticity were averaged over both

directions , the oriented panels averaged higher than the random panels. Internal bond of all panels after accelerated aging exposure decreased from the initial acceptable internal bond (greater than 70 psi) to below 30 psi.

For 200- and 300-pound concentrated loads applied 2-1/2 inches from the edge on 1- and 3-inch disks, respectivel, oriented and random panels had similar deflection values. However, failure loads applied on the disks were higher for the random panels than for the oriented panels. Also, the random panels retained more strength after a 3-day water spray than the oriented panels. In general, the oriented panels deflected less than random panels in tests of distributed load over a 24-inch span. For a 16-inch span, dry-tested 5/8-inch random panels deflected less than oriented panels.

Oriented and random mixed species flakeboard had less impact resistance than southern pine plywood. Oriented flakeboards of 1/2-inch thickness had less impact resistance than random flakeboards of this thickness. In 5/8-inch thickness, random mixed species flakeboards tested wet had greater impact resistance than oriented flakeboards; when tested dry oriented boards of this thickness had greater impact resistance.

Introduction

The Southern Forest Experiment Station's efforts at using forest residues for structural flakeboards focuses on underused hardwoods growing on southern pine sites. Hse et al. (5) indicated that two methods of constructing three-layer pressed boards made from flakes produced on a shaping-lathe headrig (6) could probably meet use requirements and Forest Service goals (8). In the first of these constructions (random), flakes are randomly oriented throughout the board; in the second (oriented), flakes on face and back are aligned with one axis of the board, while core flakes are randomly placed. Test panels 18 inches square and 1/2-inch thick were fabricated in the laboratory according to the specifications proposed by Hse et al. (5). The panels' strength properties are tabulated on the following page.

---

[1]Stationed at Pineville, La.

Small test panels were fabricated
with relative ease; it is more difficult,
however, to lay up and press commercial
4- by 8-foot panels. Research indicated
that the larger panels could be fabricated;
but, a small percentage decrease in
strength properties should be expected

Board property	Oriented	Random
Board density, pcf	45.5	47.5
Bending stiffness (MOE), thousand psi	1,090	800
Bending strength, psi	6,600	5,300
Internal bond, psi	82	83

(7). Commercial production might therefore
require heavier or thicker boards to
compensate.

In this study 4- by 8-foot panels of
various densities and thicknesses were
fabricated. Evaluation of plate shear,
bending, internal bond, and 24-hour water
soak specimens cut from the 4- by 8-foot
boards are discussed in Part I. Part II
discusses panel behavior under concen-
trated, distributed, and impact loadings
of 4- by 4-foot sections.

Part I

Shear, Strength, and 24-Hour
Water-Soak Tests

Experimental Procedure

Fabrication

Panels were a mix of 20 percent each
by weight of hickory (Carya sp.), white
oak (Quercus alba L.), southern red oak
(Q. falcata var. falcata), sweetgum (Liqui-
dambar styraciflua L.), and southern pine
(Pinus sp.). Flake and panel specifica-
tions are in Table 1. The 4- by 8-foot
panels were manufactured with: a) random
face and core flakes and b) oriented face
and core flakes. Also, 4- by 8-foot,
single-species, random-flake panels were
fabricated using either yellow-poplar
(Liriodendron tulipifera L.) or loblolly
pine (Pinus taeda). Mixed species panels
were made 1/2- and 5/8-inch thick; those
of single species were made in the 1/2-
inch thickness only.

Oriented panels were fabricated with
specially formulated resin (4) in the
pilot plant of Potlatch Corp. at
Lewiston, Idaho. The panels were made in
a double-opening press 8.5 feet long.
These 1/2- and 5/8-inch panels were
pressed for the same amount of time as the
random panels, 7.5 and 9.5 minutes but at
lower temperature and specific mat
pressure--340°F and 450 psi.

Density

Panel density depended on the m[
of fabrication, flake orientation, a[
species mixture. Panel density, in [
was based on weight and volume at ab[
6 percent moisture content. Twenty-[
random panels were fabricated at eac[
the following densities.

Species	Densit[
	1/2-in. panel
	------pcf
Mixed species	47, 49
Yellow-poplar	43.5
Loblolly pine	45.

Thickness	Density
	pcf
1/2 in.	46.6, 51.3
5/8 in.	45.6, 47.9

Tests

From each density group, eight
were chosen at random and cut into t
4-foot-square sections. One section
reserved for the concentrated and di
tributed load tests discussed in Par
The other 4-foot section was dissect
into small-size test specimens (Fig.

Plate shear specimens, 17.5 in
square, were tested according to AST
3044-72 (3). Bending, internal bond,
24-hour water soak tests were conduc
according to ASTM D 1037-72 (2), wit
the addition of a modified aging tes

Four sets of three bending spe
were taken from each 4- by 4-foot se
of panel (Fig. 1). From each set, a
original-condition (65 percent RH at
72°F), accelerated-aging and modifie
aging specimen was randomly selected
Fifteen-inch test spans were used fo
1/2-inch-thick bending specimens, an
18-inch spans for 5/8-inch specimens

Internal bond specimens used fo
65 percent RH, accelerated aging, an
modified aging tests were removed fr
bending specimens. Internal bond sa
used for the 50 percent RH tests wer
from the 4- by 4-foot sections of pa
(Fig. 1).

pecimens. Internal bond samples used for
ne 50 percent RH test were cut from the 4-
y 4-foot sections of panel (Fig. 1).

The modified-aging regime consisted
f three complete cycles of:

1) Immersing in water at 120°±3°F
for 6 hours.

2) Heat in dry air at 210°±3°F for
18 hours.

efore testing, material was conditioned
t 72°±3°F and RH of 65°±1 percent for at
east 1 week.

Statistical analysis

Linear regressions were used for
omparing board constructions and thick-
ess. All differences were statis-
ically significant at the 0.005 level of
robability. When comparing properties
hat have a significant linear relation-
hip with density, comparisons are made
t 46 pcf densities for mixed-species
anels and 42 pcf for single-species
anels.

Results

Plate shear

At a density of 46 pcf, the shear
odulus of the random panels, 259,000 psi,
s 35 percent higher than that of the
riented panels, 192,000 psi. The regres-
ion slopes of panel density on shear
odulus are statistically equivalent for
oth 5/8-inch panels and the 1/2-inch
andom panel (Table 2). Since the slope
f the 1/2-inch oriented panels was not
quivalent to the 1/2-inch random panel,
t higher or lower densities the 35 per-
ent difference in shear moduli will not
e maintained.

Based on regressions calculated for
density of 46 pcf (Table 3), oriented
anels have better bending properties
han random panels if both the 8-foot
nd 4-foot directions are averaged, even
hough oriented panels were pressed at
ower pressure and cold-cut flakes were
sed. In the 8-foot direction, oriented
anels have better bending properties
han random panels; in the 4-foot direc-
ion random panels have the better
ending properties (Table 4). The direc-
ional effects held for both 1/2- and
/8-inch thicknesses. Bending properties
f 1/2-inch mixed species panels were
ower than those of 5/8-inch panels.

When directional property ratios
DPR), that is, the bending strength or
odulus for the 8-foot direction divided
y that for the 4-foot direction, equals
0, complete randomization is achieved.
he higher the ratios, the better the

orientation. The DPR of 5/8-inch panels
was greater than that of 1/2-inch panels,
indicating an increase in directional
property difference with increased thick-
ness.

Random mixed species panels had DPR's
of 1.15 in bending strength (MOR) and 1.21
in modulus of elasticity (MOE). Single-
species panels averaged 1.21 and 1.26 for
MOR and MOE. These DPR's indicate that
the forming system at FPL caused a small
degree of orientation.

Oriented panels had a DPR of 1.79 in
bending strength and 2.70 in MOE, so
Potlatch's orienting equipment was success-
ful in orienting the flakes. Visual
analysis indicated that the oriented
panels' DPR was influenced by two factors.
First, the alignment mechanism for core
flakes functioned better than the
mechanism for face flake alignment.
Second, a consistent feed rate at the mat
forming station could not be obtained,
resulting in an unbalanced core-face ratio.

In general, modified aging did not
reduce bending properties as much as the
ASTM accelerated aging (Table 5). For
the mixed-species panels at 46 pcf,
60 percent and 78 percent of the bending
strength was retained after accelerated
and modified aging, respectively.
Single-species panels retained 93 and
95 percent of their bending strength
after exposures.

Since MOR and MOE after aging are
based on the specimen's original dimen-
sions, substantial swelling during aging
may indicate either a loss or gain in
strength and stiffness, which is reflected
mostly in the MOE values (Table 5).

Internal bond

The internal bond (IB) at 46 pcf
was not affected by the orientation of
the flakes (Table 6). Internal bond was
affected by thickness and was the only
property tested for which 1/2-inch boards
had better values than 5/8-inch boards.
However, internal bond of the 5/8-inch
boards could be improved by a longer press
time and greater pressure. Also, face
densification on all panels could have
been improved by greater pressure.

The pressing schedules used did not
significantly densify the face of the
panels, which yielded a uniform density
profile throughout the panel thickness.
Most IB failure of mixed-species panels,
regardless of exposure condition and panel
thickness, occurred in the face flakes
(Table 7). Because of the uniform density
profile, sanding before testing would
probably not have decreased the incidence
of face-flake failures. The experimental-
ly determined linear relations (Table 6)
indicated that to obtain an IB strength
of 70 psi, density of 1/2-inch mixed
species panels must exceed 43 pcf and

5/8-inch panels must exceed 47 pcf.

As exposure induced weathering or moisture increased. IB decreased (Table 8). Increasing RH from 50 to 65 percent decreased IB an average of 7.6 psi because of moisture increase or density decrease or both. Modified aging and accelerated aging reduced IB strength drastically. The average modified aging strength (13.5 psi) is only 21 percent of the 65 percent RH average. Accelerated aging reduced the IB an additional 8 percent. For the mixed-species panels, only 10 percent of the 65 percent RH strength was retained after accelerated aging, but the single-species panels retained 28 percent. An improvement in aged IB should improve other properties and may decrease the property differences discernible after modified and accelerated aging exposure.

24-Hour soak

Linear regressions on density of percent water absorbtion based on weight gain (WAW), and percent thickness swell per percent moisture content increase (TM) were significant for mixed-species panels. Comparisons among regressions (slopes) indicate that panel thickness did not affect the density relationships. But, flake orientation was significant. Combining the panel thicknesses for each flake orientation, linear regressions for WAW and TM on density (ρ) are:

Panel type	Linear regression	R^2	$Sy\cdot\rho$
Random	WAW=70.37-1.12ρ	0.663	2.651
	TM=-3.78+0.183ρ	.553	.546
Oriented	WAW=99.81-1.48ρ	.537	4.267
	TM=-2.35+0.136ρ	.350	.608

The dimensional stability was influenced by the fabrication variables. Random panels' linear expansion (LE) is larger in the 4-foot direction, while the oriented panels have the largest LE's in the 8-foot direction (Table 9). As previously discussed, equivalent layer orientation or randomization and balanced layer flake quantity was not obtained. If the three-layered mats had been fabricated with cores and faces of equal weight and equally well aligned, then the linear expansion values would have been equal in both directions.

Part II

Concentrated, Distributed and Impact Load Evaluation

Procedure: Concentrated and Distributed Loading

The eight 4-foot-square sections per density group that remained after the original 4- by 8-foot panels were cut, were randomly divided into two groups. The sections were tested for concen-

trated and distributed loads; one group was tested on 16-inch joist-type spacing and the other on 24-inch spacing. Panel sections used for the 24-inch spacing were cut in the panel's original 8-foot direction to yield two 2- by 4-foot pieces. Panels for the 16-inch spacing were obtained by removing 16 inches from the inside edge (an edge that had been part of the interior of the original 4- by 8-foot panel) of a 4- by 4-foot section, and then cutting the section in half in the 8-foot direction. This left two 24- by 32-inch sections for testing. One piece of each section to be used for the 24-inch and 16-inch spacings was designated for a wet test; the other, for a 50 percent RH test (dry).

For the wet test, panels were exposed to a continuous 3-day water spray applied to the top surface (loading surface) of the panel. While they were sprayed, panels were inclined vertically. Spray heads were calibrated to apply about 6 gallons of water per hour to each panel. After the spray, panels were nailed to framing members and evaluated within 8 hours for initial concentrated load deflections, distributed load, and concentrated load to failure in the same sequence as the dry test panels.

All panels were nailed to nominal 2- by 8-inch, kiln-dried, No. 2 (or better) grade, southern pine framing (Fig. 2); the 8-foot dimension of the panel spanned the framing members. Panels were attached with 8d common nails spaced about 6 inches on center and about 3/8 inch from the edge along outside framing members. Nails were 12 inches on center on the middle framing member. A nominal 1- by 4-inch board was nailed to the lower part of each end of the frame to prevent rotation of the structure.

For the concentrated load test of panels on 24-inch spans, a disk 3 inches in diameter was placed at mid-span 2-1/2 inches from the panel's outside edge (an edge on the outside of the original 4- by 8-foot panel) (Fig. 2). A 300-pound load was applied to the disk at 0.20 inch per minute. Once the 300-pound load was removed, a 1-inch disk was placed 2-1/2 inches from the edge, directly across the span from the first load. A 200-pound load was applied to the disk at 0.20 inch per minute. Next, the load was removed and another 200-pound load on a 1-inch disk was applied 2-1/2 inches from the same edge as the original 300-pound load but on the opposite span. The final load was 300 pounds on a 3-inch disk applied to the remaining edge.

For testing the 16-inch spans, a 200-pound load was applied first, then two 300-pound loads, and a final 200-pound load. In all cases, deflection of the underside of the panel at the point of load was continuously recorded. The

eflection measuring device was fastened
o that deflection readings were relative
o the joists.

Within a few hours after the con-
entrated load tests, 2,000-pound
istributed loads were applied twice to
he panels. With each load, panel de-
lection at the center of span was re-
orded relative to the joist.

After the distributed load test, the
anels were subjected to concentrated
oads to failure. Procedures for loading
he panels were the same as those used
n the earlier concentrated load tests.

esults: Concentrated and
istributed Loading

The only failure in all of the con-
entrated load tests was a low density
/2-inch oriented mixed species panel
valuated under the wet condition. The
oad was applied to this panel as a 3-inch
isk and was located next to an outside
dge. Failure occurred at 260 pounds.

When the inside and outside edge
alues and both densities (highest two
ensity groups for 5/8-inch random mixed
pecies panels) were averaged, the
riented and random panels had statis-
ically equivalent (0.05 level) deflec-
ions for equal thicknesses (Table 10).
he largest differences between random
nd oriented panels occurred in the wet
est. In this test, the deflection of
riented panels exceeded that of random
anels for all 24-inch spans and one
6-inch span.

Failure loads on random panels sig-
ificantly exceeded failure loads on
riented panels under wet and dry condi-
ions. Also, the random panels retained
ore of their dry strength. For example,
he 24-inch-span, random panels evaluated
et retained 81 percent of their dry
trength, oriented panels retained 74 per-
ent. For 16-inch spans, random panels
etained 74 percent and oriented panels
etained 62 percent of their dry strength.
n fact, for the 24-inch span, the failure
oad of the random panels when wet was
bout equal to the failure load of the
riented panels when dry.

Oriented panels usually deflected
ess and sustained more weight when a
oad was applied near the inside edge
han when it was applied near the outside
dge (Table 11). Although the case was
ot as clear for random panels, the out-
ide edge tended to be stronger than the
nside. In most cases, as the density
f random panels increased deflection
iminished and maximum load rose. In
ontrast, several cases occurred where
/2-inch oriented panels evaluated on
4-inch spans deflected more and sup-
orted less weight as panel density in-
reased.

All 1/2-inch panels evaluated on
24-inch spans deflected less than 0.25
inch when dry tested and more than 0.35
inch when wet tested. The 5/8-inch
panels on 24-inch spans had less than
0.25-inch and 0.38-inch average deflection
for dry and wet tests. By increasing
panel thickness from 1/2 to 5/8 inch,
panel deflection for 200- and 300-pound
loads was reduced about 40 percent for
both wet and dry conditions. Failure load,
applied on 1- and 3-inch disks, increased
at least 25 percent with the 1/8-inch in-
crease in panel thickness. The relation-
ships held for the 16-inch spans except
for maximum load applied to wet panels
on a 3-inch disk.

By decreasing the span from 24 inches
to 16 inches, the deflection caused by a
200-pound load applied on a 3-inch disk
decreased 2.5 times for the dry test and
2.3 times for the wet test. The shorter
span also increased the weight of failure
loads, the amount depending on the loading
disk, test condition , and panel construc-
tion. In general, dry-test load on panels
increased 21 percent, and wet-test load
increased 19 percent.

The 200-pound uniform load equalled
250 psf on panels nailed over 24-inch
spans and 375 psf on panels nailed over
16-inch spans. Although the longer span
supported less weight per square foot,
the deflection ratio of 24-inch to 16-
inch spans was 5.0 for the dry test and
5.7 for the wet test. For the 24-inch
span, random mixed species panels
deflected more than oriented panels under
wet and dry conditions. The 1/2-inch
random and oriented panels deflected
about the same when dry-tested on 16-inch
spans. In the wet-test, 1/2- and 5/8-inch
random panels deflected more than oriented
ones. The 5/8-inch random panels
deflected less than oriented panels when
dry tested.

Procedure: Impact Loading

Six panels from each density group
were chosen at random for impact evalua-
tion. The only 5/8-inch random mixed
species panels used were from the two
low-density groups. Nineteen southern
pine plywood panels of two thicknesses
(1/2-inch with three plies and 5/8-inch
with four plies) were purchased from six
building suppliers in central Louisiana.
A 1/2-inch and 5/8-inch panel from each
supplier was randomly selected for impact
evaluation.

All 1/2-inch panels were cut into 4-
by 4-foot sections; 5/8-inch panels were
cut to obtain one 48- by 32-inch piece
from each end. One section was used for
dry test (50 percent RH condition). The
other section was designated for a 3-day
water spray before evaluation. The water-
spray cycle consisted of the same regime

as in the concentrated-load test, and all panels were nailed to frames as described in the concentrated-load section. All 1/2-inch panels were evaluated on 24-inch spans; the 5/8-inch panels were evaluated on 16-inch spans.

Both spans of each panel were tested. Impact locations were at mid-span 6 inches inward from the edge (Fig. 3). A 200-pound load was applied to a 3-inch disk at the designated impact location before each drop of the impact load and after failure. The deflection resulting from the concentrated load was recorded relative to the joist. After removal of the concentrated load, a leather bag containing enough No. 9 lead shot to total 30 pounds was released by a remote-controlled solenoid-activated pair of jaws. The drop bag conformed to ASTM E 72-68 (1). The first drop height was 6 inches and height was increased in 6-inch increments until the panel would not support the 200-pound load or a failure was observed. The maximum drop height (MDH) was recorded, and the deflection caused by each drop was recorded relative to the joist.

Results: Impact Loading

Southern pine plywood had greater average impact resistance than any of the flakeboard panels (Table 12). However, yellow-poplar flakeboards that were wet tested had a higher impact resistance than plywood that was wet tested. Only the 1/2-inch oriented mixed species flakeboards had a deflection at maximum drop height that was less than that of plywood.

Considerable variation was observed in the impact resistance of different plywood panels and between locations on one panel. For instance, the 5/8-inch plywood that was dry-tested had an average MDH on the inside edge of 56 inches (range of 18 to 90 inches) and an average on the outside edge of 84 inches (range of 66 to 120 inches) (Table 13). The 1/2-inch plywood had a more consistent average MDH (64 inches for both edges), but the range was 36 to 78 inches for the outside edge and 12 to 102 inches for the inside edge.

Among flakeboards, yellow-poplar panels had the greatest and 1/2-inch oriented panels the least impact resistance. Results for random pine panels were similar to those for random mixed species panels. The 5/8-inch random flakeboard had a higher MDH than similar oriented flakeboard for the wet test but a lower MDH for the dry test. The difference may have occurred because of excessive thickness swell and water absorption by the oriented panels.

Except for yellow-poplar flakeboards, the impact resistance and deflection of

1/2-inch panels in the dry test were similar to those in the wet test. Am 5/8-inch panels, the random panels and plywood had more impact resistance whe wet than when dry tested. Oriented pa and plywood deflected more when wet te than when dry tested.

After impact failure, all panels ported the 200-pound concentrated load Except for a few cases, the deflection ratio--final deflection/initial deflec --exceeded 1.50 but was greater than 1 only for the wet 5/8-inch oriented mix species flakeboards. Among 1/2-inch panels, plywood had the lowest deflect ratio for both wet and dry conditions. But the ratio for 5/8-inch random flak board was less than that for 5/8-inch plywood for the dry test and equal for wet test.

The 200-pound concentrated load caused less initial deflection for all types of flakeboards than for plywood equal thicknesses were compared. Afte failure, the plywood deflected slightl less than flakeboard of equal thicknes except for the dry tested 1/2-inch yel poplar flakeboards and wet tested 5/8-oriented mixed species flakeboards.

References

1. American Society for Testing and Materials. 1968. Conducting strengt tests of panels for building construc tion. ASTM Desig. E 72-68. ASTM, Philadelphia, Pa.

2. American Society for Testing and Materials. 1975. Standard methods o evaluating the properties of wood-bas fiber andparticle panel materials. A Desig. D 1037-72a. ASTM, Philadelphi Pa.

3. American Society for Testing and Materials. 1976. Standard method of test for shear modulus of plywood. A Desig. D 3044-76. ASTM, Philadelphia

4. Hse, C.-Y. 1975. Formulation of economical fast-cure urea phenolic re for exterior hardwood flakeboard. In Proc. 9th WSU Particleboard Symp. Wa ington State Univ., Pullman, Wash.

5. Hse, C.-Y., P. Koch, C.W. McMill and E.W. Price. 1975. Laboratory s development of a structural exterior flakeboard from hardwoods growing on southern pine sites. For. Prod. J. 25(4):42-50.

6. Koch, P. 1975. Shaping-lathe he now commercially available. South. Lumberman 231(2872):93-97.

7. Price, E.W. 1975. Initial test large panels of structural flakeboar from southern hardwoods. In Proc. 9t Symp. Washington State Univ., Pullma

8. Schaffer, E.L. 1974. Forest res into structural particleboard: A Fo Service national program. American Society of Agricultural Engineers Pap No. 74-1548. ASAE, St. Joseph, Mich

Table 1.--FLAKE AND PANEL FABRICATION SPECIFICATIONS FOR 4- BY 8-FOOT STRUCTURAL FLAKEBOARDS

Property	Specifications
Flake generation	From 6-in. bolt on shaping lathe
Flake length	3 in.
Core flakes	0.025-in.-thick, milled for width reduction
Face flakes	0.015-in.-thick, random bolts heated to $160^{\circ}F$ oriented bolts at ambient temperature
Flake moisture content	3 to 4%
Mat construction	Layered with each face 1/4 of total weight
Surface treatment	Sprayed 4.32 g of water/ft^2 surface area
Resin binder	6% liquid phenol-formaldehyde resin (4)
Wax	1% wax solids from wax emulsion

Table 2.--SUMMARY OF SHEAR MODULUS AND REGRESSION EQUATIONS

Flakeboard Panel Type	Number of Test Specimens	Moisture Content	Density[1] ρ	Shear Modulus G	Linear Regression, $G = a + b\rho$			
					a	b	R^2	$Sy \cdot \rho$
		%	Pcf	Thousand psi				
1/2-inch oriented mixed species	16	10.34	42.55	173.84	- 90.157	6.131	0.840	8.395
	16	9.78	46.85	193.95				
1/2-inch random mixed species	16	10.24	46.31	261.57	-122.291	8.302	.670	13.213
	16	10.17	48.00	276.80				
5/8-inch oriented mixed species	16	10.02	41.09	155.41	-155.924	7.573	.861	9.855
	16	10.30	45.48	188.40				
5/8-inch random mixed species	16	10.01	42.60	235.94	- 91.683	7.622	.777	12.601
	16	9.99	45.46	252.52				
	8	10.20	49.48	288.24				
1/2-inch random pine	16	10.66	41.95	266.89	N.S.			
1/2-inch random yellow-poplar	16	9.50	42.25	301.30	N.S.			

[1] Density based on OD weight and volume at test.

Table 3.--REGRESSION RELATIONSHIP BETWEEN DENSITY AND BENDING PROPERTIES

Panel Type	Exposure Conditions	Panel Direction	$\sigma = a + b\rho$[1]				$E = a + b\rho$[1]			
			a	b	R^2	$S_{y\cdot\rho}$	a	b	R^2	S_y
		Ft.	----------Psi----------				--------Thousand psi-----			
1/2-inch oriented mixed species	65% RH	8	-4846	223	.642	616	-633.78	34.80	.746	74.
		4	-2358	124	.735	232	- 67.90	9.68	.536	27.
	Modified aging	8	-7986	267	.813	525	-1252.70	45.88	.931	51.
		4	-4409	150	.659	318	-750.92	24.15	.355	96.
	Accelerated aging	8	-6990	237	.749	420	-1384.30	48.71	.943	52.
		4	-2498	107	.640	233	-321.13	14.44	.455	45.
1/2-inch random mixed species	65% RH	8	-8122	286	.583	519	-870.64	34.37	.633	56.
		4	- 800	109	.317	542	42.62	11.12	.292	58.
	Modified aging	8	-8320	270	.543	552	-608.47	27.45	.389	76
		4	-5642	199	.505	416	-744.03	27.77	.666	41.
	Accelerated aging	8	-7024	232	.724	349	-1126.70	39.01	.750	54.
		4	-4152	159	.530	379	-764.09	28.29	.765	39.
5/8-inch oriented mixed species	65% RH	8	-8157	302	.549	881	-906.85	42.02	.596	111.
		4	-2712	124	.449	411	-141.28	10.49	.413	37.
	Modified aging	8	-9505	297	.642	697	-1472.60	50.60	.574	137.
		4	-3451	123	.487	346	-315.06	13.57	.558	32.
	Accelerated aging	8	-5095	183	.539	565	-1055.70	38.66	.520	123
		4	-2557	120	.724	249	-157.31	9.29	.286	37.
5/8-inch random mixed species	65% RH	8	-4606	212	.644	541	-226.39	20.91	.542	66.
		4	-4329	190	.732	376	-444.06	23.29	.583	64.
	Modified aging	8	-4169	179	.760	360	-515.52	26.16	.774	50.
		4	-4034	166	.641	420	-693.51	28.20	.712	59.
	Accelerated aging	8	-2012	113	.544	373	-337.90	15.48	.269	91.
		4	-1921	84	.310	320	-419.01	16.49	.291	86.
1/2-inch random pine	65% RH	8	-5944	263	.721	547	-583.99	31.02	.856	42.
		4	-1230	122	.611	363	-222.20	18.76	.798	35.
	Modified aging	8	-2492	164	.621	404	-708.69	33.53	.694	70.
		4	-3286	171	.725	352	-371.91	22.22	.711	47.
	Accelerated aging	8	-5037	225	.643	570	-649.18	31.94	.774	58.
		4	N.S.				-502.53	25.39	.528	64.
1/2-inch random yellow-poplar	65% RH	8	-3196	217	.729	637	-448.91	30.96	.831	67.
		4	-7728	310	.804	351	-583.76	30.02	.742	40.
	Modified aging	8	-3537	221	.561	757	-733.93	38.26	.744	87.
		4	-5642	255	.634	526	-580.75	30.21	.594	67.
	Accelerated aging	8	-5140	262	.694	757	-1054.43	48.53	.829	96
		4	-4741	230	.568	536	-619.80	31.70	.649	62.

[1] σ = bending strength; ρ = density based on OD weight and volume at 65% R.H.; E = modulus of elasticity.

CENTER LINE
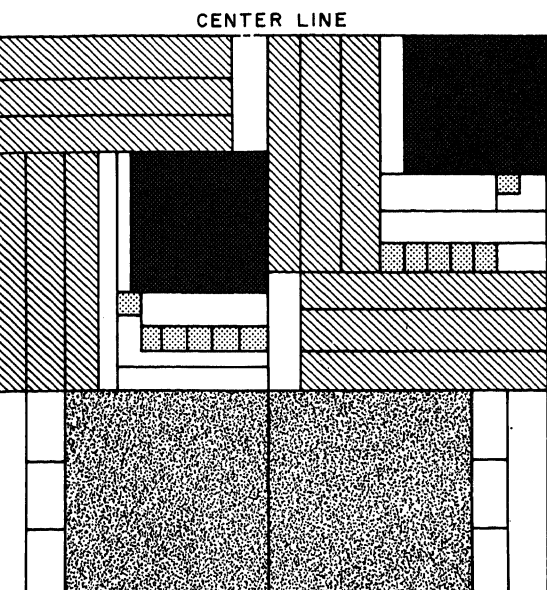
Figure 1.--Diagram for cutting test specimens from full-size panels.

▨ BENDING

▦ INTERNAL BOND

▩ PLATE SHEAR

■ WATER ABSORPTION
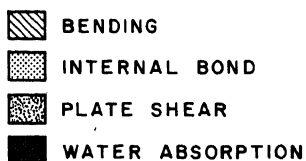
Table 4.--CALCULATED BENDING PROPERTIES OF PANELS PRESSED TO A DENSITY OF 46 PCF[1]

Panel Type	Panel Direction	Exposure Condition		
		65% RH	Modified aging	Accelerated aging
BENDING STRENGTH, Psi				
1/2-inch oriented	8	5412	4296	3912
mixed species	4	3346	2491	2424
1/2-inch random	8	5034	4100	3648
mixed species	4	4214	3512	3162
5/8-inch oriented	8	5735	4157	3323
mixed species	4	2992	2207	2963
5/8-inch random	8	5146	4065	3186
mixed species	4	4411	3602	1943
1/2-inch random	8	5102	4396	4413
pine	4	3894	3896	
1/2-inch random	8	5918	5745	5864
yellow poplar	4	5292	5068	4919
MODULUS OF ELASTICITY, Thousand psi				
1/2-inch oriented	8	967.02	857.78	856.36
mixed species	4	377.38	359.98	343.11
1/2-inch random	8	710.38	654.23	667.76
mixed species	4	554.14	533.39	537.25
5/8-inch oriented	8	1026.07	854.97	722.66
mixed species	4	341.26	309.16	270.03
5/8-inch random	8	735.47	687.84	374.18
mixed species	4	627.28	603.69	339.53
1/2-inch random	8	718.85	699.57	692.30
pine	4	565.72	561.33	563.85
1/2-inch random	8	851.41	872.99	983.83
yellow-poplar	4	677.08	688.07	711.60

1   Density based on ovendry weight and volume at 65% RH.

109

Table 5.--SUMMARY OF BENDING PROPERTIES

	65% RH Test Condition				After Modified Aging[2]			After Accelerated Aging[2]		
	Moisture content	Density at test[1]	Bending strength	Modulus of elasticity	Density	Bending strength	Modulus of elasticity	Density	Bending strength	Modulus of elasticity
	%	Pcf	Psi	Thousand psi	-----------------------		%	-----------------------------		
8-FOOT DIRECTION										
1/2-in. oriented mixed species	10.86	42.68	4831	866.89	79.9	77.9	87.8	73.8	67.8	81.5
	10.39	47.75	5676	1009.57	79.5	76.9	86.3	72.5	70.1	87.7
1/2-in. random mixed species	10.68	43.13	4314	609.55	80.4	76.8	100.1	73.4	68.8	90.4
	10.66	45.68	4852	701.48	78.2	84.2	91.7	71.3	71.6	91.2
5/8-in. oriented mixed species	10.64	42.82	4655	776.04	77.3	68.0	87.0	72.2	54.1	74.5
	10.33	46.33	5999	1060.48	75.2	72.3	85.0	65.8	55.0	58.0
5/8-in. random mixed species	10.91	39.10	3748	606.05	83.5	75.2	83.9	77.7	61.7	39.6
	10.79	41.69	4026	639.85	81.0	77.7	87.7	74.6	63.6	55.1
	10.58	45.78	5526	736.90	80.3	78.4	95.0	73.1	60.4	41.5
1/2-in. random pine	11.27	39.28	4384	634.45	88.0	91.8	101.5	83.5	83.8	92.7
1/2-in. random yellow-poplar	10.68	39.44	5375	772.10	83.8	96.6	100.3	84.4	91.5	105.0
4-FOOT DIRECTION										
1/2-in. oriented mixed species	10.63	42.67	2909	346.70	79.5	76.9	83.4	73.9	69.3	81.6
	10.43	47.32	3554	388.97	79.2	84.1	102.2	72.4	69.3	89.9
1/2-in. random mixed species	10.63	44.13	4043	530.34	79.7	87.7	92.9	74.4	69.2	86.0
	10.56	46.15	4300	572.71	78.5	79.4	92.5	71.2	67.0	88.2
5/8-in. oriented mixed species	10.76	42.48	2440	302.14	77.0	71.9	86.3	72.2	63.7	75.1
	10.41	45.65	3027	340.04	75.0	76.5	93.0	65.5	64.7	78.9
5/8-in. random mixed species	10.90	39.39	3274	484.17	83.4	76.2	87.6	78.5	64.3	41.5
	10.88	42.04	3611	550.20	80.5	75.7	83.4	74.6	62.8	52.4
	10.66	45.47	4274	574.27	80.4	90.6	112.5	73.4	72.5	55.0
1/2-in. random pine	11.64	39.54	3594	519.48	86.3	101.5	102.3	82.8	127.2	100.2
1/2-in. random yellow-poplar	10.74	39.39	4493	598.40	82.8	100.5	103.9	78.0	92.6	106.8

[1] Density based on OD weight and volume at test.
[2] Average percent retention of the initial values.

Table 6.--REGRESSION EQUATION RELATING DENSITY TO INTERNAL BOND STRENGTH OF MIXED-SPECIES PANELS[1]

Panel Types and Exposure Conditions	IB at 46 pcf	Linear Regression, IB = a + bρ			
		a	b	R^2	$Sy \cdot \rho$
		------------------------Psi----------------------			
1/2-inch oriented					
50% RH	91.8	-170.36	5.70	0.508	13.50
65% RH	83.0	-112.03	4.24	.442	16.03
1/2-inch random					
50% RH	84.2	-223.55	6.69	.505	7.98
65% RH	79.2	- 59.74	3.02	.176	18.77
5/8-inch oriented					
50% RH	74.1	-241.05	6.85	.572	14.54
65% RH	64.1	-158.10	4.83	.442	16.70
5/8-inch random					
50% RH	75.1	-206.43	6.12	.598	12.56
65% RH	67.4	- 99.56	3.63	.466	13.03

[1] Density based on OD weight and volume at test.

Table 7.--PERCENT INTERNAL BOND FAILURES OCCURING AT DESIGNATED LOCATIONS FOR 1/2-INCH PANELS CONDITIONED AT 50% RH

Board Type and Density	Failure Location[1]			
	F	C	I	L
Pcf	----------------------%--------------------			
Oriented				
43.22	59.4	31.2	9.4	0
46.75	89.1	3.1	7.8	0
Random				
46.59	56.3	35.9	7.8	6.3
47.92	59.4	23.4	17.2	4.7
Pine				
43.38	28.1	64.1	7.8	4.7
Yellow-poplar				
42.40	26.6	65.6	7.8	6.3

[1] F = face   I = face-core interface
     C = core   L = large folded flake occupying at least
                         30% of failure surface.

Table 8.--SUMMARY OF INTERNAL BOND PROPERTIES FOR FLAKEBOARD PANELS SUBJECTED TO VARIOUS EXPOSURES

Panel Types	50% RH		65% RH		Modified Aging		Accelerated Aging	
	Density[1]	IB	Density[2]	IB	Density[2]	IB	Density[2]	IB
	Pcf	Psi	Pcf	Psi	Pcf	Psi	Pcf	Psi
1/2-inch oriented mixed species	43.22	77.4	42.67	71.1	43.24	12.8	42.46	7.6
	46.75	95.0	47.54	86.8	47.16	19.5	46.43	11.6
1/2-inch random mixed species	46.59	88.7	43.63	72.8	44.21	13.0	42.78	6.6
	47.92	96.4	45.92	81.6	45.98	14.3	45.36	7.5
5/8-inch oriented mixed species	43.72	57.4	42.65	44.0	42.46	5.7	42.43	4.3
	47.56	85.4	45.99	70.0	46.70	7.6	45.49	5.5
5/8-inch random mixed species	42.19	52.6	39.25	41.3	38.99	6.6	38.56	4.9
	44.61	65.7	42.35	54.4	41.77	7.8	41.20	5.2
	48.42	90.7	45.63	71.1	46.21	10.4	45.50	6.4
1/2-inch random pine	43.38	71.5	39.40	59.7	40.22	24.9	39.54	17.1
1/2-inch random yellow-poplar	42.40	68.3	39.41	65.1	39.62	25.7	38.58	17.1
Av.	45.16	77.2	43.21	65.3	43.33	13.5	47.57	8.5

[1] Density based on OD weight and volume at 50% RH.
[2] Density based on OD weight and volume at 65% RH.

Table 9.--DIMENSIONAL STABILITY MEASURED BY 24-HOUR WATER SOAK

Panel Type and Density	Water Absorbtion	Thickness Swell		Linear Expansion	
				8-Foot direction	4-Foot direction
Pct	%	%	%/% MC [1]	------------- %-------------	
1/2-in. oriented mixed species					
43.63	30.0	20.8	0.338	0.085	0.030
48.30	36.4	17.8	.383	.079	.020
1/2-in. random mixed species					
43.95	21.4	13.2	.454	.055	.090
45.68	21.0	13.2	.445	.062	.101
5/8-in. oriented mixed species					
42.54	36.6	22.7	.463	.193	.143
47.16	27.8	19.o	.351	.190	.129
5/8-in. random mixed species					
38.77	26.7	13.3	.342	.058	.116
42.03	22.5	12.0	.383	.028	.057
47.07	17.1	9.6	.428	.065	.085
1/2-in. random pine					
40.37	27.3	12.9	.331	.020	.053
1/2-in. random yellow-poplar					
39.42	20.5	9.9	.372	.025	.035

[1] The % thickness swell per % change in moisture content.

Figure 2.--Diagram of test location for the concentrated load evaluations.

INSIDE EDGE

2 1/2"

S/2

S/2

24"

2 1/2"

OUTSIDE EDGE

S

2" x 8" BOARD

TEST PANEL

1" x 4" BOARD

S — SPAN

● — 1" DIAMETER LOCATION FOR 200 POUND LOAD

O — 3" DIAMETER LOCATION FOR 300 POUND LOAD
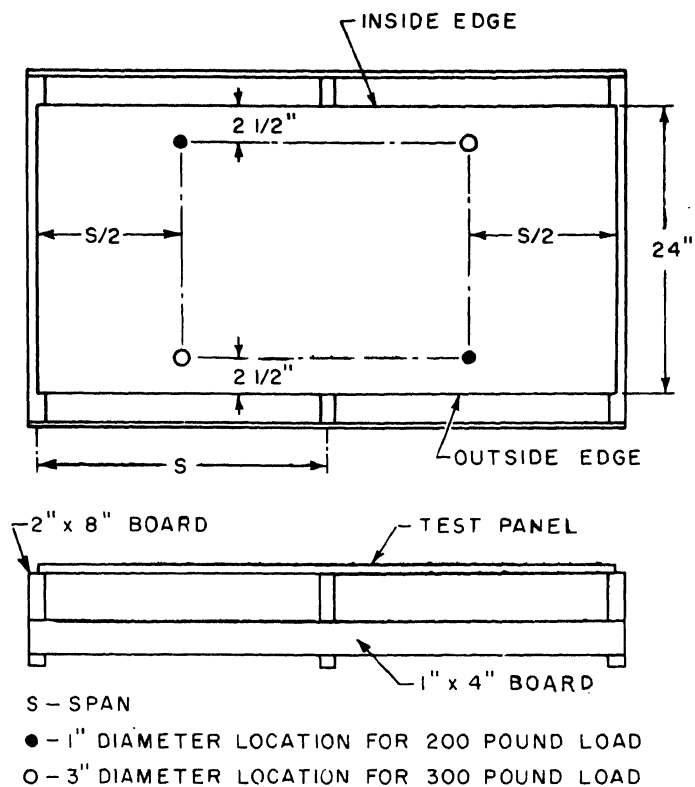
Figure 3.--Diagram of test location for impact test.

6"

S/2

OUTSIDE EDGE

INSIDE EDGE

48"

S/2

6"

S

S — SPAN

O — LOCATION FOR IMPACT AND 200 POUND LOADING
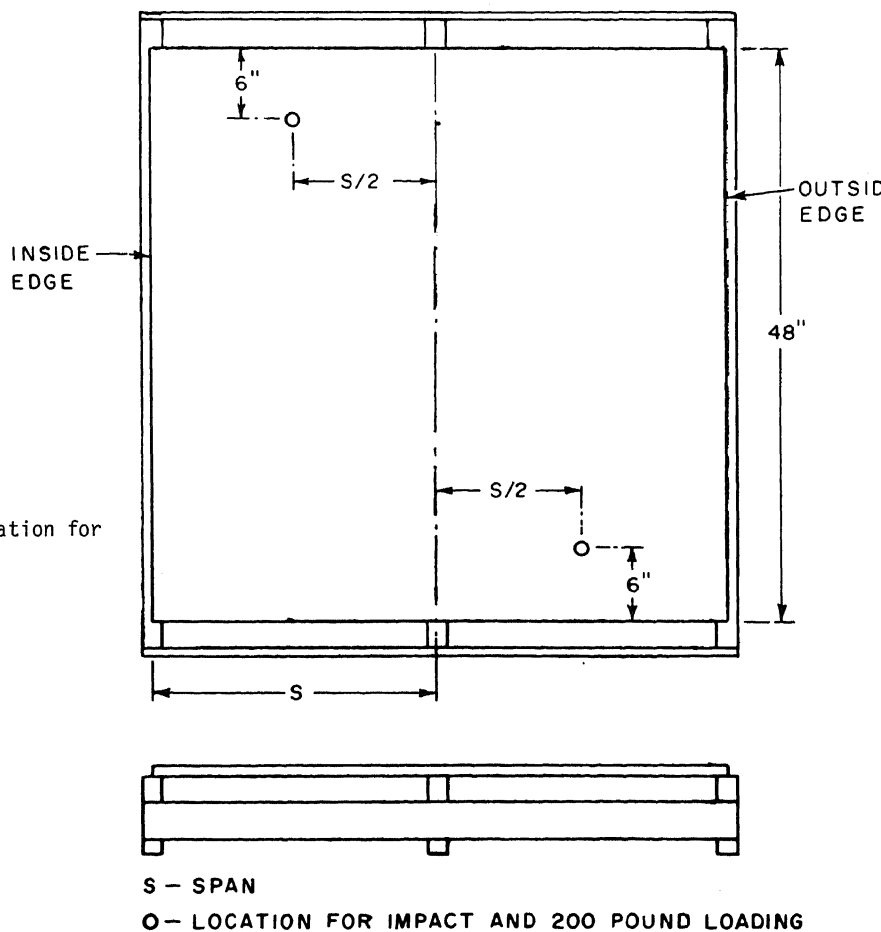
Table 10.--AVERAGE DEFLECTION, MAXIMUM CONCENTRATED LOADS, AND AVERAGE DEFLECTION FOR UNIFORM APPLIED LOAD FOR MIXED SPECIES FLAKEBOARDS

Panel Type	Load Applied Through a 1-Inch Disk				Load Applied Through a 3-Inch Disk				Deflection at 2000-Pound Uniform Load	
	Deflection at 200 pounds		Maximum load		Deflection at 300 pounds		Maximum load			
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
	-----In-----		-----Lb-----		-----In-----		-----Lb-----		-----In-----	
					24-INCH SPAN					
1/2-inch oriented	0.311	0.461	442	301	0.452	0.708	573	388	0.189	0.245
1/2-inch random	.313	.452	567	433	.442	.667	672	575	.249	.334
5/8-inch oriented	.184	.269	658	416	.260	.413	769	514	.115	.150
5/8-inch random	.187	.258	764	630	.277	.409	938	740	.146	.188
					16-INCH SPAN					
1/2-inch oriented	.133	.185	598	364	.188	.275	748	494	.039	.043
1/2-inch random	.126	.198	678	509	.188	.292	850	612	.040	.062
5/8-inch oriented	.073	.122	817	510	.105	.177	1015	600	.032	.026
5/8-inch random	.076	.114	905	700	.105	.177	1173	861	.027	.032

TABLE 11.--FLAKEBOARD DEFLECTION AND LOAD CARRYING CAPACITY FOR CONCENTRATED APPLIED LOADS AND DEFLECTION WITH A 2,000-POUND DISTRIBUTED LOAD

Panel Type and Density (Pcf)	Load Applied Through a 1-Inch Disk — Deflection at 200 pounds (In) Dry II	Dry OI	Wet I	Wet 0	Maximum Load (Lb) Dry I	Dry 0	Wet I	Wet 0	Load Applied Through a 3-Inch Disk — Deflection at 300 pounds (In) Dry I	Dry 0	Wet I	Wet 0	Maximum Load (Lb) Dry I	Dry 0	Wet I	Wet 0	Deflection at 2000-Pound Distribution Load (In) Dry	Wet	Moisture Content at Test (%) Dry	Wet
24-INCH SPAN																				
1/2-inch oriented mixed species																				
44.0	0.287	0.322	0.422	0.530	515	386	325	314	0.427	0.452	0.621	0.725[3]	650	473	364	302	0.183	0.248[3]	6.5	84.2
48.1	.325	.310	.398	.494	455	480	289	276	.457	.470	.673	.690	625	543	353	374	.195	.242	6.4	69.5
1/2-inch random mixed																				
46.6	.337	.302	.468	.485	504	575	405	423	.483	.456	.757	.644	620	611	488	543	.263	.356	5.6	54.1
47.8	.317	.296	.435	.420	545	644	474	429	.412	.415	.660	.607	728	729	616	653	.235	.311	5.7	33.8
5/8-inch oriented mixed species																				
43.3	.187	.182	.258	.379	665	543	409	354	.294	.261	.392	.611	744	648	496	456	.122	.188	6.4	91.6
47.0	.167	.198	.217	.222	788	636	452	450	.232	.251	.290	.358	928	754	620	484	.108	.111	6.4	77.6
5/8-inch random mixed species																				
42.1	.212	.199	.309	.278	690	723	466	513	.285	.289	.473	.423	753	848	603	563	.153	.198	5.9	54.5
43.3[2]	.191	.187	.284	.269	659	776	435	531	.302	.283	.473	.402	813	916	559	608	.156	.199	6.2	53.8
48.2[2]	.204	.167	.248	.228	800	818	650	903	.273	.248	.370	.390	955	1065	918	875	.136	.176	5.9	27.1
1/2-inch random pine																				
43.2	.361	.285	.484	.456	445	578	378	380	.528	.414	.718	.634	590	675	487	535	.263	.342	6.0	68.4
1/2-inch random yellow-poplar																				
40.8	.292	.273	.357	.378	611	630	520	495	.445	.399	.568	.564	691	781	594	639	.223	.262	5.9	30.3
16-INCH SPAN																				
1/2-inch oriented mixed species																				
44.1	.118	.152	.175	.180	608	564	379	359	.171	.214	.248	.293	854	650	473	473	.037	.043	6.9	80.0
48.7	.134	.127	.157	.227	640	580	423	295	.177	.188	.241	.314	785	704	574	453	.040	.043	6.4	65.0
1/2-inch random mixed species																				
45.3	.123	.134	.222	.207	696	648	491	458	.177	.189	.314	.301	808	876	489	543	.038	.065	6.7	49.5
46.7	.119	.128	.182	.178	738	630	521	564	.178	.194	.293	.259	871	843	728	688	.042	.058	6.9	43.7
5/8-inch oriented mixed species																				
43.3	.068	.076	.112	.135	825	611	498	438	.098	.120	.159	.222	1006	764	497	456	.032	.031	6.5	85.1
48.2	.073	.076	.102	.140	925	906	594	510	.097	.104	.136	.189	1214	1075	771	676	.033	.020	6.5	75.7
5/8-inch random mixed species																				
41.0	.106	.089	.158	.135	725	778	554	599	.117	.122	.212	.171	1003	801	614	765	.021	.037	6.8	59.5
43.9	.092	.084	.126	.129	759	825	627	614	.117	.110	.196	.174	1148	1109	700	845	.036	.029	6.5	54.7
44.3	.059	.068	.099	.101	1103	933	845	715	.096	.097	.161	.176	1265	1168	868	1030	.017	.035	6.8	40.7
1/2-inch random pine																				
42.0	.105	.150	.202	.190	821	500	474	467	.159	.204	.320	.291	985	734	563	581	.046	.062	6.9	73.8
1/2-inch random yellow-poplar																				
40.8	.104	.122	.159	.154	858	630	501	681	.161	.182	.247	.211	1016	889	724	915	.041	.051	6.3	25.9

1 I = inside edge; 0 = outside edge.
2 Average of two panels instead of four panels.
3 The average of three panels.

Table 12.--AVERAGE IMPACT TEST AND 200-POUND CONCENTRATED LOAD EVALUATION ON FLAKEBOARDS AND PLYWOOD PANELS. THE RATIO OF FLAKEBOARD TO PLYWOOD IS INSIDE THE PARENTHESES.

Panel Type	Moisture Content at Test (%)		Maximum Drop Height		Deflection at Maximum Drop (In)		Deflection with 200-Pound Concentrated Force (In)			
							Initial		Final	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
					24-INCH SPAN					
1/2-inch oriented mixed species	6.94 (1.00)	74.36 (1.85)	35 (.55)	31 (.52)	0.195 (.90)	0.196 (.91)	0.207 (.96)	0.258 (.94)	0.339 (1.06)	0.441 (1.28)
1/2-inch random mixed species	5.78 (.83)	32.57 (.81)	51 (.80)	56 (.93)	.220 (1.01)	.220 (1.02)	.210 (.98)	.252 (.92)	.326 (1.02)	.368 (1.07)
1/2-inch pine plywood	6.94	40.12	64	60	.217	.215	.215	.274	.321	.344
1/2-inch random pine	6.65 (.96)	61.94 (1.54)	52 (.81)	55 (.92)	.227 (1.05)	.215 (1.00)	.193 (.90)	.240 (.88)	.332 (1.03)	.384 (1.12)
1/2-inch random yellow-poplar	5.49 (.79)	25.41 (.63)	60 (.94)	72 (1.20)	.224 (1.03)	.257 (1.20)	.180 (.84)	.208 (.75)	.311 (.97)	.345 (1.00)
					16-INCH SPAN					
5/8-inch oriented mixed species	6.96 (1.08)	88.15 (2.08)	64 (.91)	56 (.62)	.171 (1.36)	.179 (1.16)	.057 (.91)	.071 (.76)	.106 (.91)	.257 (1.65)
5/8-inch random mixed species	6.08 (.94)	28.95 (.68)	58 (.83)	77 (.86)	.188 (1.49)	.187 (1.21)	.055 (.87)	.067 (.71)	.085 (.73)	.112 (.72)
5/8-inch pine plywood	6.44	42.37	70	90	.126	.154	.063	.094	.117	.156

Table 13.--FLAKEBOARD AND PLYWOOD IMPACT PROPERTIES AND DEFLECTION RESULTING FROM A 200-POUND CONCENTRATED LOAD APPLIED BEFORE AND AFTER IMPACT EVALUATION

Panel Type and Density	Maximum Drop Height				Deflection at Maximum Drop				Deflection with 200-Pound Concentrated Force							
	Dry		Wet		Dry		Wet		Initial				Final			
									Dry		Wet		Dry		Wet	
	I	O	I	O	I	O	I	O	I	O	I	O	I	O	I	O
					--- In ---											
							24-INCH SPAN									
1/2-inch oriented mixed species 44.0 46.9	32 42	33 32	27 34	26 36	0.194 .219	0.187 .178	0.191 .192	0.199 .200	0.206 .205	0.202 .214	0.250 .250	0.279 .250	0.362 .330	0.338 .326	0.479 .382	0.475 .427
1/2-inch random mixed species 43.6 45.4	45 55	50 53	48 59	64 54	.225 .219	.219 .216	.212 .223	.250 .195	.212 .214	.212 .199	.268 .240	.250 .247	.342 .319	.336 .303	.391 .336	.383 .360
1/2-inch pine plywood 34.1	64	64	68	51	.216	.217	.235	.195	.229	.200	.253	.294	.331	.310	.315	.373
1/2-inch random pine 41.3	49	55	53	57	.214	.240	.203	.227	.194	.191	.246	.233	.328	.335	.401	.367
1/2-inch random yellow-poplar 40.6	59	61	62	81	.225	.223	.249	.265	.187	.173	.210	.206	.322	.299	.358	.331
							16-INCH SPAN									
5/8-inch oriented mixed species 41.9 46.1	59 69	57 71	51 58	55 61	.150 .183	.219 .131	.167 .158	.218 .172	.060 .054	.058 .057	.072 .063	.075 .073	.114 .077	.156 .077	.240 .196	.306 .286
5/8-inch random mixed species 42.2 44.1	51 57	58 66	73 77	78 78	.173 .183	.188 .208	.188 .192	.169 .200	.058 .054	.056 .051	.070 .066	.070 .061	.085 .072	.080 .101	.110 .099	.135 .100
5/8-inch pine plywood 33.3	56	84	82	97	.114	.137	.141	.167	.066	.060	.099	.088	.109	.124	.161	.151

[1] I = inside edge; O = outside edge.

MANUFACTURE AND PERFORMANCE OF FULL-SIZE STRUCTURAL
FLAKEBOARDS FROM DOUGLAS-FIR FOREST RESIDUES

J. Dobbin McNatt[1]
Technologist
Forest Products Laboratory
USDA Forest Service
Madison, Wisconsin

Abstract

The Forest Products Laboratory manufactured
and assessed the performance of 4- by 8-foot
structural flakeboard panels from Douglas-fir
forest residues after target performance goals
were developed. The 42 pcf, three-layer
boards were 1/2 inch thick with high quality disk
cut flakes for the faces and lower quality flakes
processed through a ring flaker in the core. More
than 200 panels were produced. Basic mechanical
and physical properties were evaluated, as well
as durability and performance under concentrated
and impact loading, racking strength of wall and
floor sections, and fire exposures. Bending
strength and stiffness were both below the target
goals. Most other goals were met; including
those for shear and nailholding properties, in-
ternal bond, and hardness. Panels used as wall
sheathing exceeded specified acceptance standards
for full-size walls. Under concentrated load,
panels met maximum load and deflection recom-
mendations of the Uniform Building Code for roofs
and floors. Under fire exposure, the panels had
a class B flame spread rating and exceeded the
fire endurance requirement for exterior walls of
one- and two-family dwellings.

Introduction

Forest residues which have been, at times,
estimated to amount to 9.6 billion cubic feet an-
nually, can be grouped into three primary cate-
gories: timber damaged by insects, disease and
fire; logging residues; and precommercial thin-
ning. Logging residues alone offer more than
three times the volume of raw material used an-
nually in the plywood industry (7).

To improve the utilization of these residues,
the U.S. Forest Service set up a national research
program to develop a structural flakeboard that
could be manufactured from this presently unused
material (8).

The goals of the research at the Forest
Products Laboratory (FPL) were to provide the
technology and procedures that would enable in-
dustry to produce a panel product made primarily
from softwood logging residues that would be

fully adequate as an exterior-grade construction
material. This paper is a summary of the fol-
lowing reports prepared as part of the Forest
Service National Structural Flakeboard Program.

1. Manufacture of full-size structural flake-
   boards - William F. Lehmann.

2. Small specimen properties of full-size struc-
   tural flakeboards from Douglas-fir forest
   residues - Matti J. Hyvarinen and Michael J.
   Superfesky.

3. Dimensional stability of FPL structural
   flakeboard - William F. Lehmann.

4. Concentrated and impact load testing of FPL's
   structural flakeboard - J. Dobbin McNatt and
   Michael J. Superfesky.

5. Racking strength of panels sheathed with
   Forest Service structural flakeboard -
   William J. McCutcheon.

6. Fire performance of structural flakeboard
   from forest residues - Carlton A. Holmes,
   Herbert W. Eichner, John J. Brenden, and
   Robert H. White.

Manufacture of Full-Size Panels

The raw materials used were primarily
Douglas-fir forest residues gathered from log-
ging operations on the western slopes of the
Cascade Mountains in Washington State and shipped
to the Forest Products Laboratory, Madison,
Wisconsin. These were primarily broken logs of
diameters varying from about 5 to 24 inches and
containing variable amounts of decay.

The materials were segregated for conver-
sion into flakes such that they contained ap-
proximately 75 percent sound wood larger than
6 inch diameter, 12-1/2 percent wood with decay,
6-1/4 percent sound wood less than 6 inches in
diameter, and 6-1/4 percent bark. The overall
flakeboard manufacturing process is outlined
in Figure 1.

The better residues were selected for face
flake material and debarked. Face flake
material was then cut into billets 2 inches
along the grain and 1 inch in width. These bil-
lets then were flaked in the laboratory disk
flaker.

The remaining residues were cut into 12 to
13 inch lengths. These lengths were fed into a
drum chipper constructed to produce chips of 1/4
to 3/8 inch thickness and 2 to 2-1/2 inches in
length. The large chips were further processed

gh a ring flaker. The following factors
ned constant during manufacture:

material--Douglas-fir forest residues
el size--0.5 x 50 x 108 in.
el density--43 pcf (target), based on oven
ry weight and nominal volume
e flakes--0.02 x 1 x 2 in. disk flakes
e flakes--0.05 x 2 x random width ring flakes
e: core flake ratio--30:70% by weight
f flakes
in binder and amount--liquid phenolic resin,
% resin solids based on ovendry weight
f flakes
type and amount--wax emulsion, 1%
ax solids based on ovendry weight of flakes
moisture content--10 ± 1%
ss cycle--10 min at 305°F, press closed
o stops in 1 min
mmed panel size--48 x 96 in.

Phenolic resin and wax were blended together
pplied to the flakes by air spray at 3 to 4
/spray gun at 40 psi atomizing air pressure.

Immediately following blending, the flakes
formed into the three-layered, 50- by 108-inch
using a simple mechanical forming device.
se of the press size, 4 by 20 feet, two mats
required for each press load. The formed
vere placed end-to-end and loaded into the
250-inch, steam-heated, 3,000-ton-capacity
ress. The press was immediately closed and
ressure cycle shown in Figure 2 was followed.
temperature was 350°F. The pressure-time
sequence shown was used to approximate as
ly as possible the press cycle normally used
small-size laboratory panels. The short
at the beginning allowed the surface flakes
t prior to the rapid application of high
ire. This then provided a high density
e to promote high stiffness. The step
ire decreases used after reaching the
ed thickness provided a means of maintaining
ness while reducing the transfer of pressure
stop bars.

In total, 216 panels were produced in this
, of which the final 151 panels were ran-
assigned to the various strength, fire,
ity, and durability tests. The initial 65
were produced to develop the procedural
ces needed to manufacture efficiently a
stent and high-quality panel product.

Basic Engineering Properties From
Small Specimen Tests

en Preparation and Testing

Basic engineering properties of the full-
Douglas-fir structural flakeboards were
ined using small-specimen tests to compare
quality with target performance goals es-
shed early in the Forest Service Structural
oard program. Properties evaluated
led bending, tension, compression, internal
shear, nail holding, hardness and impact.
were conducted on specimens conditioned
at 65 percent RH. Some
were also conducted after 24-hour water-

soak and after accelerated aging.   Overall
density and density gradient were also deter-
mined. Tests were performed according to ap-
plicable ASTM Standards (2,3). Sixty-five of
the final 151 panels were randomly selected for
small specimen tests and the small specimens
were cut both parallel to and perpendicular to
the panel length from randomly selected areas of
each of the 65 panels.

Results

The static bending and nail-holding proper-
ties are summarized in Tables 1 and 2; the hard-
ness, impact resistance (falling ball tests),
internal bond strength, strength in tension and
compression parallel to surfaces, and shear in
Table 3.

Equilibrium moisture content at 65 percent
relative humidity averaged 8.0 percent, and
density averaged 41.6 pcf as determined
from static bending specimens. Density gradient
through the panel thickness is shown in Figure 3,
as determined from selected specimens.

Both modulus of rupture (MOR) and modulus
of elasticity (MOE) in bending indicated that
the Forest Service structural flakeboard had
some directional properties despite the random
flake orientation. Averages along and across
the forming direction were 4,700 and 4,260 psi
in MOR and 714,000 and 673,000 psi in MOE,
respectively.

Forest Service Flakeboard
and Target Values

The target values (Table 4) were met or
exceeded for modulus of rupture after aging
(the actual value was 84 percent of the dry
value vs. the target value of at least 50 per-
cent), lateral nail-holding dry (503 vs. 300
pounds) and wet (332 vs. 150 pounds), nail-head
pull-through (460 vs. 250 pounds), near minimum[2]
Janka ball hardness (765 vs. 500 pounds),
internal bond strength dry (111 vs. 70 psi),
edgewise shear strength (1,630 vs. 1,000 psi),
interlaminar shear strength (395 vs. 250 psi),
direct nail withdrawal resistance dry (73 vs.
40 pounds) and wet (58 vs. 25 pounds).

However, the target values were not met for
the density range, from near minimum to near
maximum[3] (36.9 to 46.2 pcf actual vs. 37.0 to
43.0 target), near minimum modulus of rupture in
static bending (3,030 vs. 4,500 psi), modulus
of elasticity in static bending (693,000 vs.
800,000 psi), near maximum Janka ball hardness
(1,481 vs. 1,200 pounds), and internal bond
strength after aging (43 vs. 50 percent).

Cyclic Humidity Exposure

Specimen Preparation

Randomly-selected 2- by 4-foot sections of
65 full-size panels were each cut into twelve

_____

[2] 5 percent lower exclusion limit.

[3] 5 percent upper exclusion limit.

3– by 12-inch specimens for determination of dimensional stability and strength retention after cyclic moisture exposure.

The 780 3 by 12 inch specimens were randomly assigned to three groups of 260 specimens with the restriction that each group received an equal number of specimens from each panel and each major panel dimension.

The three groups of 260 specimens then were subjected to the following exposures and determinations of dimensional stability (water absorption (WA), thickness swelling (TS), and linear expansion (LE)) and related properties:

1. Ovendry exposure. 260 specimens were ovendried at 216 ± 4°F and weighed and measured.
2. Relative humidity (RH) exposure. 30 to 50 to 90 percent RH followed by 12 cycles of 30 to 90 percent RH. Specimens were placed in conditioning rooms at 80°F and appropriate humidity and maintained for 30 days during each step of the initial 30 to 50 to 90 percent RH exposure. Succeeding cycles of 90 to 30 to 90 percent RH were in 21-day increments at each step of the cycle. Specimens were weighed and measured at cycles 1, 3, 6, and 12; then 65 specimens representing both major panel dimensions were removed, dried at 120°F for 3 days and tested without further conditioning for retention of bending stiffness, strength and internal bond strength. Testing procedures conformed to ASTM D 1037–72a[4] and bending property calculations were based on initial specimen thickness.
3a. Watersoak exposures. 24-hour watersoak (WS) in 70°F water followed by 24 cycles of 1-hour soaking in 150°F water and 22 hours of drying at 160°F. Specimens were weighed and measured at cycles 1, 3, 6, 12, and 24; after each cyclic series 26 specimens were removed, dried for 3 days at 120°F and tested without further conditioning for retention of strength. All watersoak tests were performed with specimens in a horizontal position under 1 inch of water.
3b. Ovendry-vacuum-pressure-soak exposures. 24 hour WS in 70°F water followed by 24 cycles consisting of 30 minutes submerged in 70°F water under a vacuum of 26 inches of Hg, 60 minutes at 50 psi pressure and 22 hours drying at 160°F. Specimens were weighed and measured at cycles 1, 3, 6, 12, and 24; after each cyclic series 26 specimens were removed, dried for 3 days at 120°F and tested without further conditioning for retention of strength.

Results

Results of these evaluations are illustrated graphically in Figures 4 to 9 and indicate that structural flakeboards as prepared in this study can undergo prolonged and reasonable exposures to cyclic wet and dry conditions with minimal loss of strength and bond integrity and with reasonable changes in dimensions. If exposures are limited to cyclic humidity conditions, there appears to be little, if any, loss in up to 12 cycles of exposure, indicating good product durability in long-term exposures to either liquid or water vapor.

Concentrated and Impact Load Testing

Specimen Preparation

Concentrated load tests were conducted on 65 randomly-selected 2 by 4 foot panels; 55 were tested "dry" after conditioning at 65 percent relative humidity, and 10 were tested "wet" after soaking in water for 24 hours. Tests were also conducted on 20 randomly-selected 4 by 4 foot panels nailed to joists after conditioning at 65 percent RH. The 2 by 4 foot panels were simply supported along the 4-foot-long sides by 4-inch-diameter steel pipes spaced 16 inches on center and resting on glued-laminated beams. A concentrated load was applied at the center of each panel, first by a 4-inch-diameter disk up to a maximum of 300 pounds; and then by a 1-inch-diameter rod up to failure. Deflection was measured relative to the supports, under the load point by a LVDT. The 4 by 4 foot flakeboard panels were nailed to 2 by 4 inch joists spaced 16 inches on center using 8-penny common nails spaced 6 inches apart. The 2 by 4 joists rested on glued-laminated beams. The concentrated load was applied to the center of one of the end spans, first by a 3-inch-diameter disk up to a maximum of 300 pounds; and then by a 1-inch-diameter rod up to failure.

For all concentrated load tests, load deflection ratios were calculated from the slope of the initial portion of the load deflection curves. Also recorded was the load at failure when loading with the 1-inch-diameter rod.

Impact load tests were conducted on 20 randomly selected 2 by 4 foot panels, 10 each "wet" and "dry" as defined above. Impact tests were also conducted on the other end span of the 20 "dry" 4 by 4 foot panels subjected to concentrated loads. An additional 5 "wet" 4 by 4 foot panels were tested. The 60-pound leather sandbag described in ASTM E 72 (5) was used in all impact tests. The 2 by 4 foot panels were simply supported along the 4-foot-long edges on the rounded tip edge of 2 by 8 inch members spaced 16 inches on center. The supports were bolted to glued-laminated girders to hold them in position during impact. The sandbag was dropped on the center of the panel.

The 4 by 4 foot panels nailed to 2 by 4 inch joists also were bolted to the glued-laminated beams to hold the panel in position during impact. The sandbag was dropped on the center of the end span of the "dry" panels not subjected to concentrated load testing and on the center of each of the two end spans of the "wet" panels.

The procedure for dropping the sandbag and measuring deflection was the same for both size panels. The bag was initially dropped from a height of 6 inches, and the height was successively increased in increments of 6 inches until failure occurred. Failure was considered to have occurred when the residual deflection exceeded 1/8 inch. After initial impact on each drop the sandbag was restrained with a rope and pulley to prevent additional impacts from the same drop. Prior to each test the sandbag was rolled on the floor to loosen the sand since packing of the sand would change the energy

orption behavior of the bag.

Deflection of the panel during impact and
idual deflection after each impact was measured
an LVDT attached to the underside of the panel
ctly under the load point by means of a ball
socket arrangement. Time-deflection data
e recorded and stored in a digital storage
illoscope. Time deflection curves for each
p were drawn by means of a digital-to-analog
verter whereby the oscilloscope memory was
yed back to an X-Y recorder at a slower sweep
e. Peak dynamic deflection, time to peak
lection, and residual deflection were read
the oscilloscope.

ults

Results of concentrated and impact load tests
given in Tables 5 and 6 and can be summarized
follows:

Concentrated Load

1. Load-deflection ratios were increased by
reasing the area under load from 1 inch in
eter to 4 inches in diameter.
2. Load-deflection ratios decreased when
flakeboard panels were soaked in water for
hours. However, load at failure changed little.
3. Load-deflection ratios were about the
e for the 2 by 4 foot simply-supported panels
the 4 by 4 foot panels nailed to joists when
4-inch-diameter loading disk was used. How-
r, the ratios were somewhat larger for the
oot-square panels than for the smaller panels
the 1-inch-diameter rod was used.
4. Performance of the panels exceeded the
mum load and allowable deflection values
ommended by the Uniform Building Code for
or and roof sheathing (9).

Impact Load

1. Neither height of drop at failure or
e to maximum deflection were affected by
ting the panels in water for 24 hours.
2. Height of drop at failure was greater
time to maximum deflection was less for the
4 foot panels nailed to joists 16 inches on
er than for the 2 by 4 foot panels simply-
orted over a 16-inch span.
3. The sand bag produced a flexure failure
g the length of the 2 by 4 foot panels, but
luced a puncture failure in the 4 by 4 foot
ls.

Racking Strength of Walls

Seven full-size 8 by 8 foot walls were
thed with FPL structural flakeboard and
ed in racking according to ASTM E 72 (5).
r were tested dry and three were tested after
g subjected to wetting cycles specified in
E72. Dry racking strength averaged just
6,200 pounds and wet strength averaged just
er 5,900 pounds. Both these values are well
e the generally accepted standards of 5,200
ds dry and 4,000 pounds wet (6).

Fire Performance

Flame spread properties of the FPL struc-
tural flakeboard were determined by the 25-foot
tunnel furnace test of ASTM E 84-70 (1).

The flame spread clsssification (FSC)
values obtained in the two tests with the FPL
structural flakeboard in the 25-foot rating
furnace were 70 and 72 with an average of 71.
This meets the acceptance flame spread criteria
under building codes for class B material--75 or
under flame spread. This classification will
permit its use in many building occupancies, and
applications where flame spread of building
materials is limited; for example, in exitways
and corridors.

The FPL flakeboard was also tested in load-
bearing wood-frame walls for fire endurance in
the Forest Products Laboratory large vertical
furnace. Two tests were conducted according to
ASTM Standard E 119-73 (1) except the panel
height was limited to 8 feet and the applied
load was 1,250 pounds per linear foot (the com-
puted maximum loading for the first floor wall
of a two-story house of average size). This was
27 percent higher than design load based on
allowable compression perpendicular to grain
stress at the plate and only 2 percent less than
design load based on allowable compression
parallel-to-grain stress in the studs. For one
wall the interior facing was 3/8-inch gypsum
wallboard panels which were vertically applied
to the frame with 1-inch-long, fourpenny gypsum
wallboard nails, spaced 8 inches on center. All
joints were taped and covered with joint com-
pound and nailheads were indented and covered
with joint compound. One coat of latex paint
was applied. For the second wall, the interior
facing was the 1/2-inch-thick flakeboard panels
vertically attached to the framing with sixpenny
nails spaced 8 inches on center at edges and
12 inches at intermediate locations.

For the wall with gypsum wallboard interior
facing, burnthrough occurred after 33 minutes,
20 seconds. The wall with flakeboard interior
facing burned through after 31 minutes, 35
seconds. Both are in excess of the 20 minutes
required for exterior walls in the Minimum
Property Standards for Single- and Double-
Family Dwellings of the Department of Housing
and Urban Development (10). Details on these
and other fire performance tests conducted on
the FPL flakeboard are given in paper No. 6
listed in the introduction.

Summary

The Forest Products Laboratory produced more
than 200 full-size (4- by 8-foot) three-layer
structural flakeboards from Douglas-fir forest
residues and evaluated their potential as an
exterior-grade construction material. Results
of tests were compared with target goals for
certain basic properties which had been developed
earlier. Target goals were not met for some
basic properties (bending strength and stiff-
ness and retention of internal bond strength
after accelerated aging, for instance), but were
surpassed for other properties (nailholding,
shear, hardness).

The following results from performance-type
testing help indicate that the panels would be
acceptable as an exterior sheathing product:

1. Under concentrated load, the panels sur-
passed the maximum load and allowable deflection
values recommended by the Uniform Building Code
for floor and roof sheathing.

2. Racking strength of full-size wall
sheathed with the panels exceeded the accepted
FHA standard.

3. Under fire exposure, panels met the ac-
ceptance flame spread criteria under building
codes for class B material. Fire endurance for
load-bearing walls sheathed with the panels ex-
ceeded the 20 minutes required for exterior walls
in the HUD minimum Property Standards for Single-
and Double-Family Dwellings (10).

References

1. American Society for Testing and Materials.
1970. Standard method of test for surface
flammability of building materials. ASTM Desig.
E 84-70. ASTM, Philadelphia, Pa.

2. American Society for Testing and Materials.
1972. Standard methods of evaluating the prop-
erties of wood-base fiber and particle panel
materials. ASTM Desig. D 1037-72a. ASTM,
Philadelphia, Pa.

3. American Society for Testing and Materials.
1972. Standard methods of test for shear modulus
of plywood. ASTM Desig. D 3044-72. ASTM,
Philadelphia, Pa.

4. American Society for Testing and Materials.
1973. Fire tests of building construction and
materials. ASTM Desig. 119-73. ASTM, Phila-
delphia, Pa.

5. American Society for Testing and Materials.
1974. Standard methods of conducting strength
tests of panels for building construction.
ASTM Desig. E 72-74a. ASTM, Philadelphia, Pa.

6. Federal Housing Authority. 1969. A standard
for testing sheathing materials for resistance to
racking. Tech. Circ. 12.

7. Lehmann, W.F. 1977. A perpetual supply of
construction sheathing panels? Plywood and Panel
17(8): 63-65.

8. Schaffer, E.L. 1976. Forest residue into
structural flakeboard: A Forest Service National
Program. Transactions Amer. Soc. Ag. Eng. 19(3):
417-421, 427.

9. Uniform Building Code. 1976 Edition.
Chapter 25, Sections 2517, h and i. International
Conference of Building Officials, Whittier,
California.

10. U.S. Department of Housing and Urban Develop-
ment. 1973 Edition. Minimum property standards
for single- and double-family dwellings. U.S. Dep.
HUD, Washington, DC.

Table 1.—STATIC BENDING PROPERTIES FOREST SERVICE STRUCTURAL FLAKEBOARD

Property	Mean	Standard Deviation	Minimum	Maximum	Coefficient of Variation	Sample Size
					%	
Original thickness, in. Specimens for dry series[1]	0.514	0.016	0.469	0.563	3	390
Original density, pcf Specimens for dry series	41.6	2.81	33.8	51.2	7	390
Moisture content, pct						
Dry (65% RH)	8.0	.7	6.0	9.6	9	390
Wet (24 hr soak)	25.5	4.0	16.1	42.5	16	130
Aged (65% RH)	9.6	.3	8.9	11.1	3	130
Modulus of rupture, psi						
Dry ||[2]	4,700	942	2,360	7,180	20	195
⊥[3]	4,260	759	2,650	6,310	18	195
All	4,480	881	2,360	7,180	20	390
Wet ||	3,620	785	2,060	6,490	22	65
⊥	3,300	637	1,930	5,100	19	65
All	3,460	730	1,930	6,490	21	130
Aged ||	3,860	686	1,670	5,070	18	65
⊥	3,540	691	2,250	5,460	20	65
All	3,700	705	1,670	5,460	19	130
Modulus of elasticity, thousand psi						
Dry ||	714	117	404	1,057	16	195
⊥	673	96	445	972	14	195
All	693	109	404	1,057	16	390
Wet ||	548	105	378	976	19	65
⊥	493	93	326	788	19	65
All	521	102	326	976	20	130
Aged ||	676	87	386	827	13	65
⊥	614	91	440	858	15	65
All	645	94	386	858	15	130

[1] Dry specimens: Conditioned to EMC at 73° F, 65% RH.

[2] \|\| Specimen length parallel to 8-ft dimension of panel.

[3] ⊥ Specimen length parallel to 4-ft dimension of panel.

Table 2.--NAIL-HOLDING PROPERTIES[1]

Property and Condition	Mean	Standard Deviation	Coefficient of Variation	Minimum Value	Maximum Value
	Lb	Lb	%	Lb	Lb
Lateral nail resistance [2]					
Dry [3]	503	82	16	209	710
Wet [4]	332	77	23	190	615
Aged [5]	381	88	23	195	650
Nail-head pull-through					
Dry	460	88	19	280	790
Wet	410	88	21	225	640
Aged	374	94	25	188	688
Direct nail withdrawal					
Dry	73	19	26	35	124
Wet	58	19	33	12	128

[1] Sixpenny common wire nail used. All values are averages of 130 specimens.
[2] 1/2-in. edge distance used.
[3] Dry: Conditioned to EMC at 73° F and 65% RH.
[4] Wet: Soaked in water 24 hr and tested wet.
[5] Aged: Subjected to 6 cycles of accelerated aging.

Table 3.—HARDNESS, IMPACT RESISTANCE, INTERNAL BOND STRENGTH, STRENGTH IN
TENSION AND COMPRESSION PARALLEL TO SURFACE, SHEAR PROPERTIES AND
SAG MODULUS OF ELASTICITY OF FOREST SERVICE STRUCTURAL FLAKEBOARD

Property	Mean	Standard Deviation	Minimum	Maximum	Coefficient of Variation	Sample Size
					%	
Janka ball hardness, lb	1,122	215	680	1,640	19	65
Falling ball impact, failure height, in.	65	6.5	48	74+	10	65
Internal bond strength, psi						
Dry	111	28	59	176	25	130
Aged	49	20	10	106	41	130
Tension parallel to surface, Modulus of elasticity, thousand psi[1]						
||	615	178	126	999	29	111
⊥	539	175	70	980	32	115
All	577	180	70	999	31	226
Tension strength, psi[1]						
||	2,024	396	1,260	3,290	20	129
⊥	1,723	309	1,090	2,630	18	130
All	1,873	385	1,090	3,290	21	259
Compression parallel to surface Modulus of elasticity, thousand psi						
||	603	114	333	885	19	130
⊥	455	89	290	702	20	130
All	529	126	290	885	24	260
Compressive strength						
||	2,690	459	1,620	4,040	17	130
⊥	2,270	377	1,450	3,340	17	130
All	2,480	469	1,450	4,040	19	260
Shear properties						
Edgewise shear strength, psi	1,630	251	1,210	2,390	15	65
Interlaminar shear strength, psi	395	73	244	641	18	65
Interlaminar shear modulus, thousand psi	44	7	31	68	16	65
Plate shear modulus, thousand psi	287	30	226	362	10	65

[1] 19 \|\| and 15 ⊥ MOE values omitted from average due to malfunction of deformation gage. One tensile strength value omitted because specimen failed in grips.

Table 4.--ACTUAL AND TARGET GOALS FOR PROPERTIES OF
DOUGLAS-FIR STRUCTURAL FLAKEBOARDS

Property	Target	Actual
Density, pcf		
Near minimum[1]	37	36.9
Near maximum[2]	43	46.2
Modulus of rupture, psi		
Near minimum[1]		
Dry (65 % RH)	4,500	3,030
After accelerated aging[3]	2,250	2,530
Modulus of elasticity, psi		
Mean	800,000	693,000
Hardness,[4] lb		
Near minimum[1]	500	765
Near maximum[2]	1,200	1,480
Internal bond		
Mean		
Dry, psi	70	113
After accelerated aging,[3] % dry	50	43
Edgewise shear strength, psi		
Mean (dry)	1,000	1,630
Interlaminar shear strength, psi	250	
Mean (dry)		395
Lateral nail resistance[5],[6], lb		
Mean		
Dry	300	503
After accelerated aging[3]	100	332
Nailhead pullthrough[5]		
Mean		
Dry	250	460
After accelerated aging	125	374
Direct nail withdrawal[5]		
Mean		
Dry	40	73
After 24-h soaking	25	58
After accelerated aging	20	--

[1] 5% lower exclusion limit.
[2] 5% upper exclusion limit.
[3] ASTM D1037-72a, Sec. 118-122. (2)
[4] Janka Ball.
[5] 6-penny common wire nail.
[6] 1/2-in. edge distance.

Table 5.--CONCENTRATED LOAD BEHAVIOR OF FPL STRUCTURAL FLAKEBOARD

Panel Type	Number	Panel Density[1]	Load-Deflection Ratio		Load at Failure: 1-inch dia. rod.
			4-inch dia. disk[2]	1-inch dia. rod.	
		Pcf	Lb/in.	Lb/in.	Lb.
2 x 4 foot, dry[3]	44				
Average		44.8	2,693	2,168	789
Range		38.5-50.1	2,083-3,333	1,705-2,752	520-975
2 x 4 foot, wet[4]	10				
Average		44.6	2,084	1,712	781
		40.6-47.1	1,648-2,381	1,339-1,935	645-935
4 x 4 foot, dry[3]	20				
Average		44.3	2,621	2,387	826
Range		41.6-46.3	2,069-3,030	1,863-2,703	665-960

[1] Density is based on weight and dimensions at 65% RH.

[2] 3-in.-diameter disk for 4- by 4-ft. panels.

[3] "Dry" panels were as conditioned to EMC at 65% RH.

[4] "Wet" panels were soaked in water for 24 hr.

Table 6.--RESULTS OF IMPACT LOAD TESTING OF FPL STRUCTURAL FLAKEBOARD

Panel Type	Number	Panel Density[1]	Height of Drop at Failure	Time to Maxium Deflection
		Pcf	In.	Ms
2 x 4 foot, dry[2]	10			
Average		44.8	27	18
Range		38.6-48.5	24-30	16-20
2 x 4 foot, wet[3]	10			
Average		44.8	29	18
Range		40.4-49.0	24-36	16-20
4 x 4 foot, dry[2]	20			
Average		44.3	36	14
Range		41.6-46.3	30-42	13-16
4 x 4 foot, wet[3]	10[4]			
Average		45.1	38	15
Range		43.0-47.2	30-42	14-16

[1] Density is based on weight and dimensions at 65% RH.

[2] "Dry" specimens were conditioned at 65% RH.

[3] "Wet" specimens were soaked under 1 in of water for 24 hr.

[4] Two tests on each of five panels.
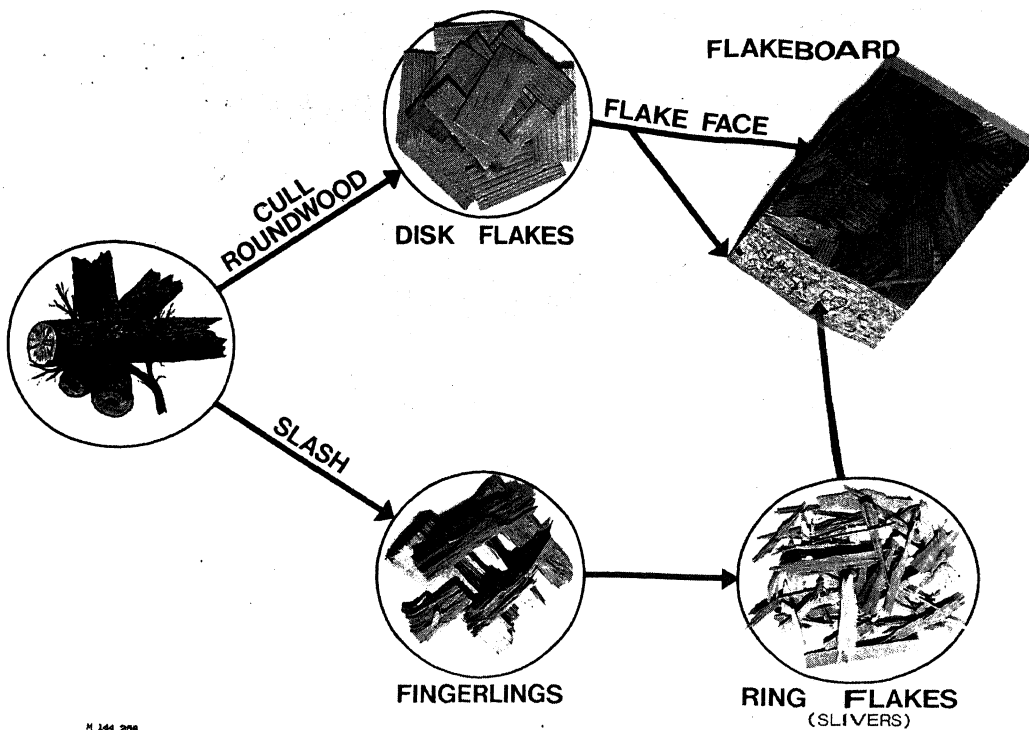
Figure 1.—The forest residues-to-structural flakeboard process.
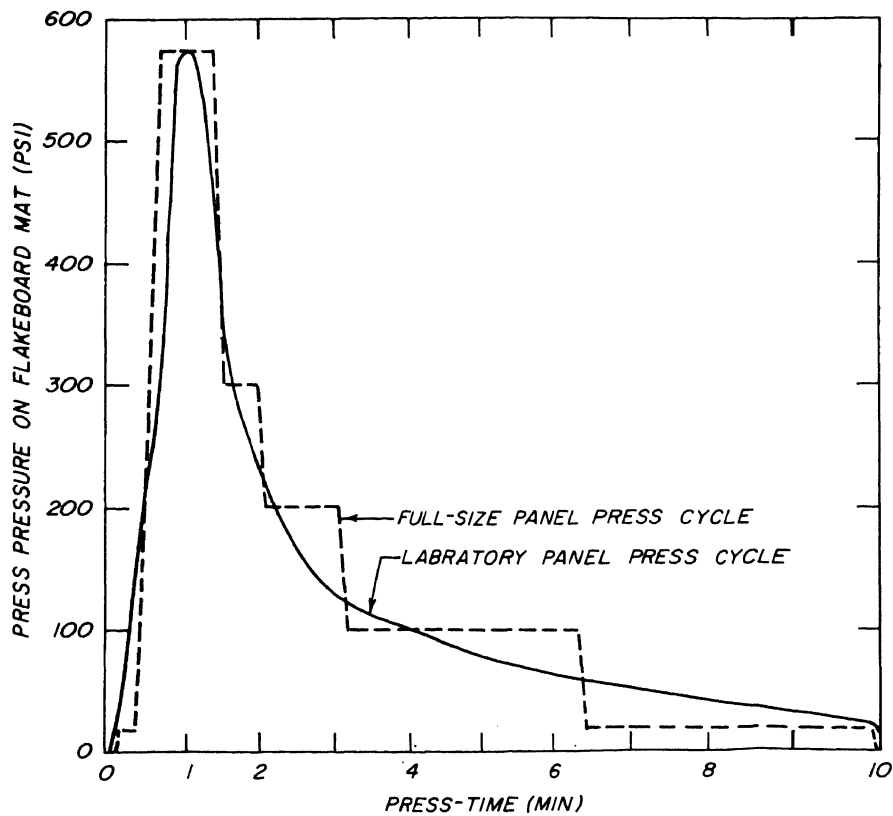
Figure 2.—Comparison of press cycles used in manufacture of laboratory
and full-size structural flakeboards.
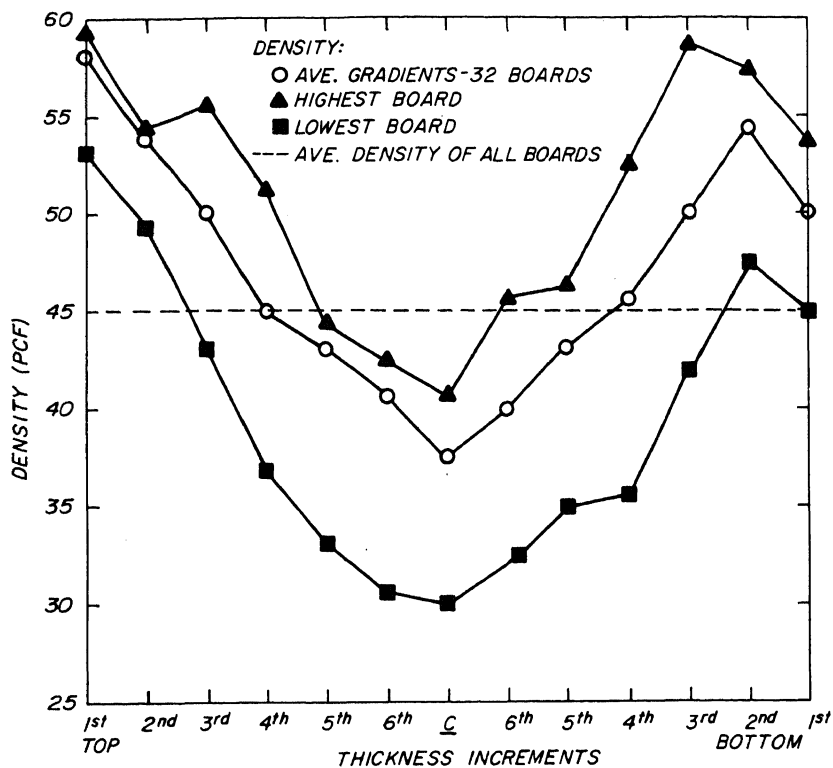
Figure 3.–Density gradients through panel thickness in FS structural flakeboards. Density is based on weight and dimensions at 73°F, 65 percent RH.
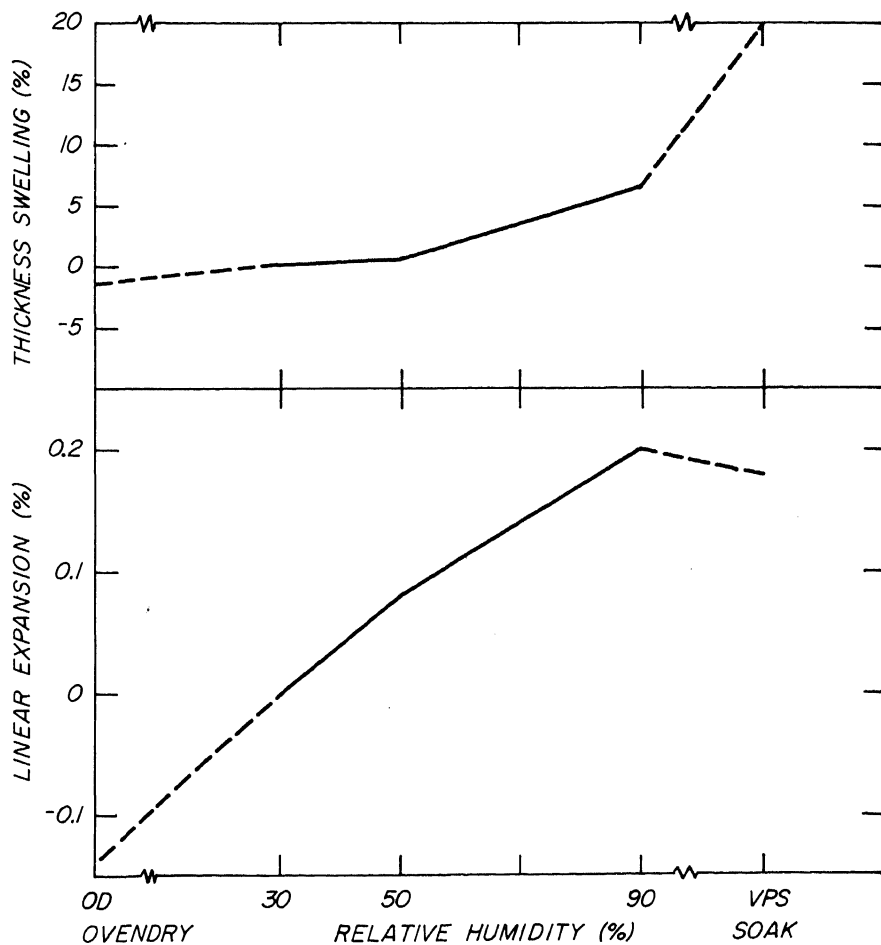
Figure 4.–Relative movement in length and thickness of FPL structural flakeboard in exposures ranging from ovendry through water saturation.
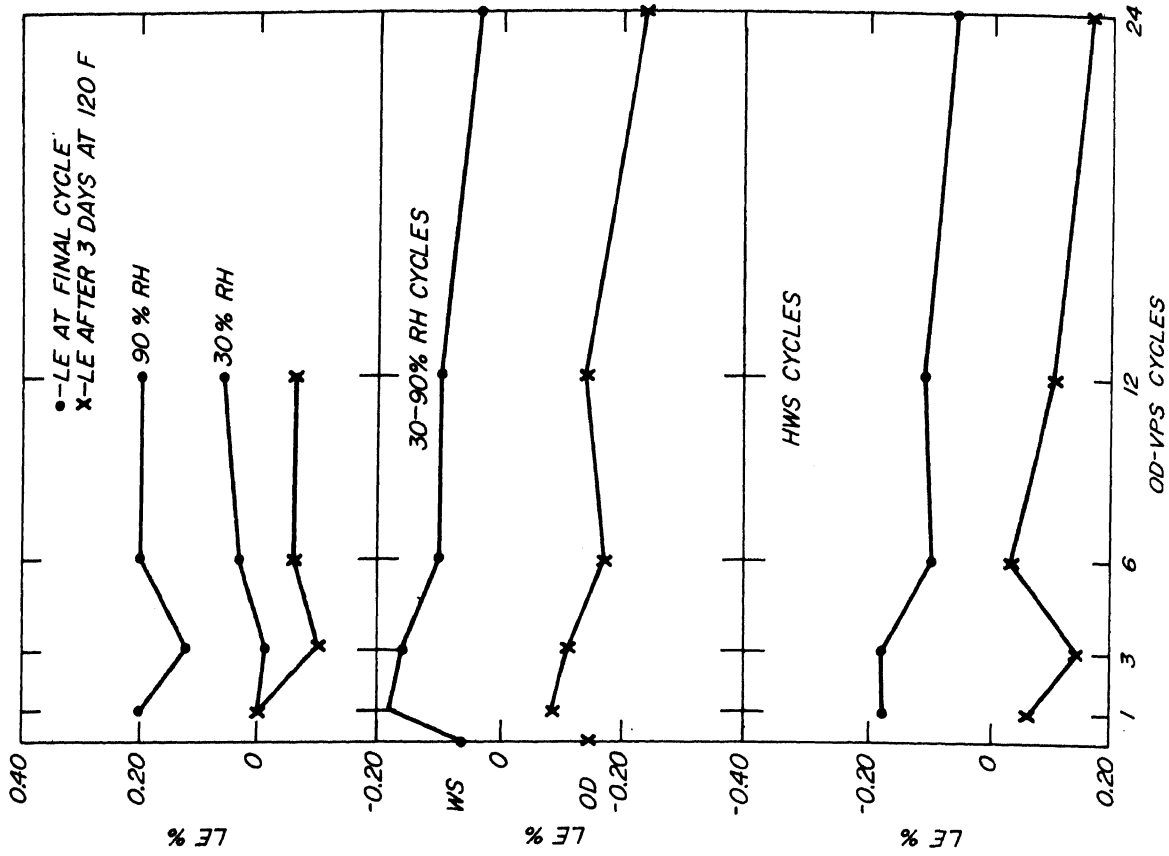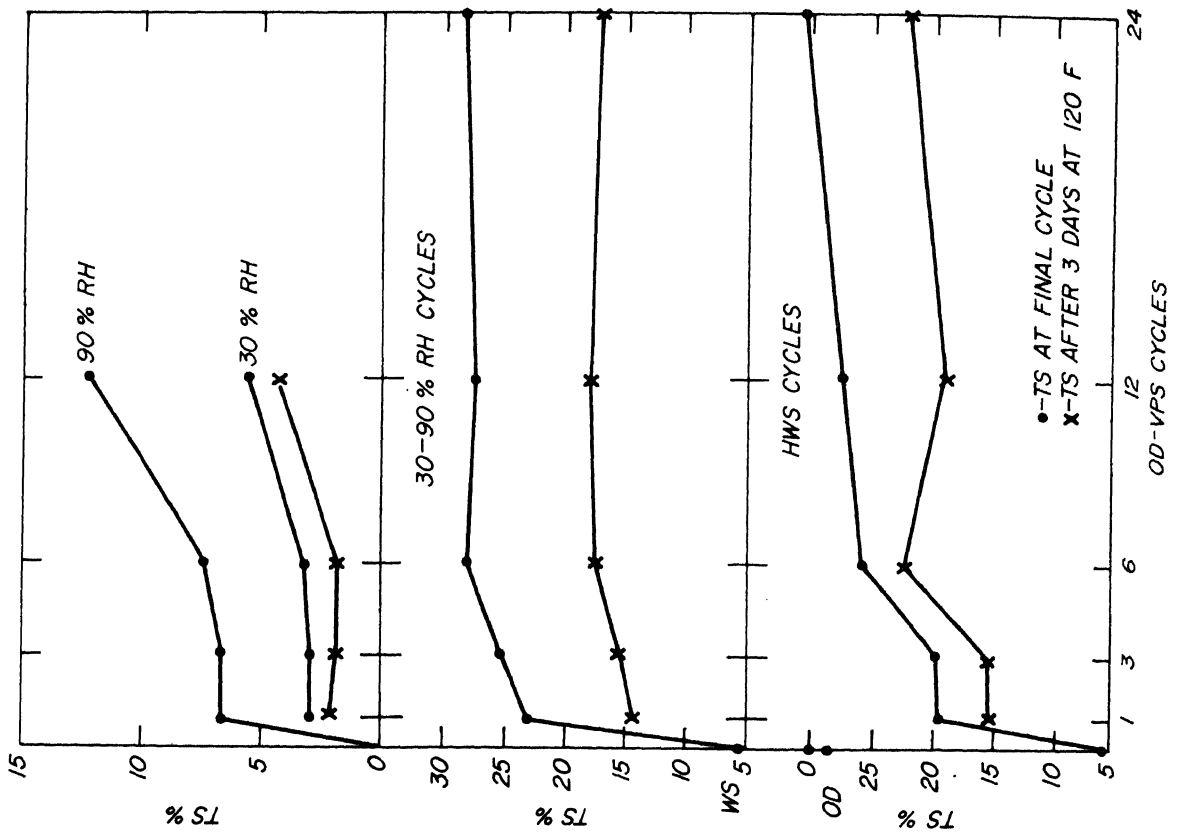
Figure 5.—Thickness swelling of FPL structural flakeboard...
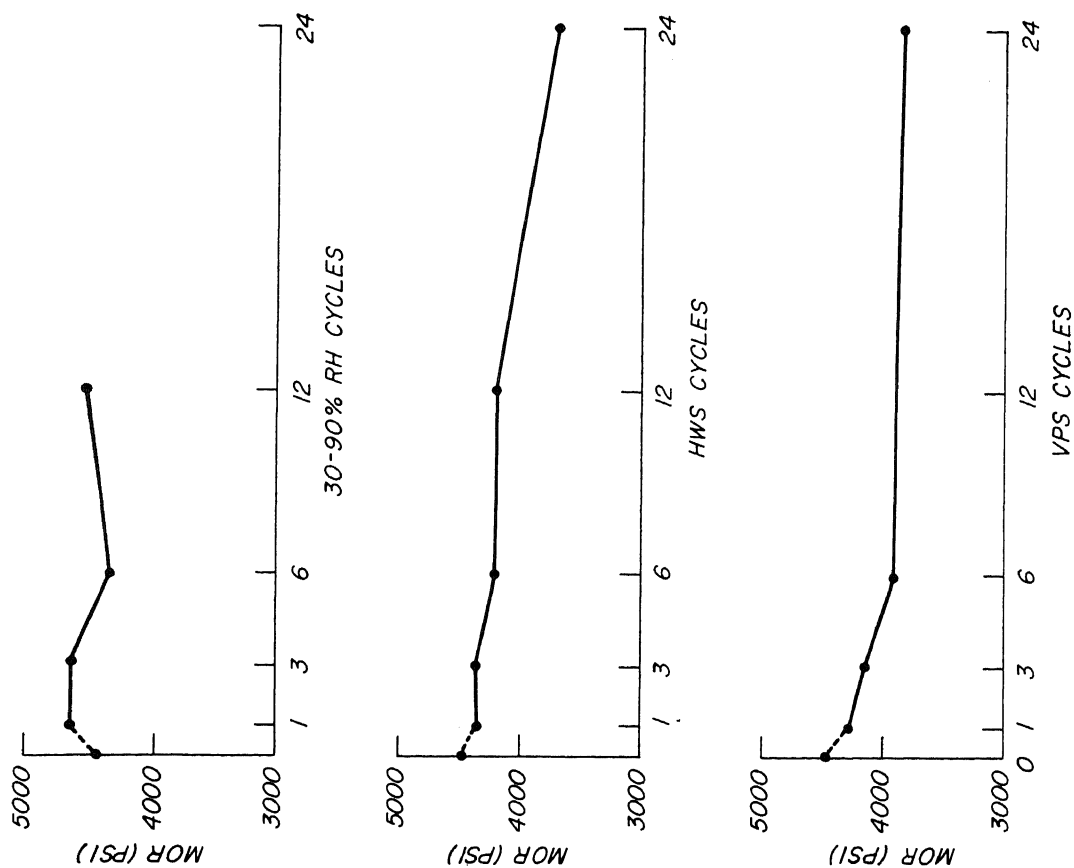
Figure 7.—Modulus of rupture of FPL structural flakeboard after exposure to 1-24 cycles of three different exposures
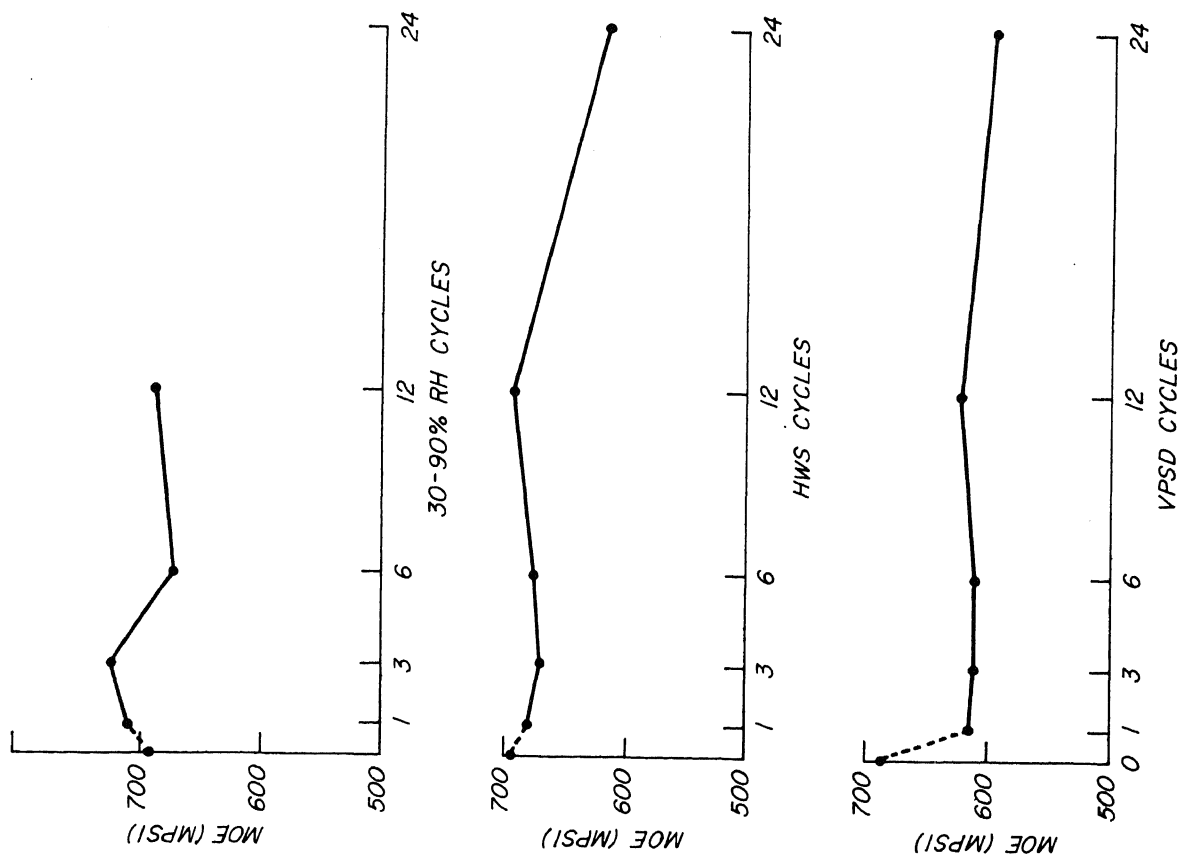
Figure 8.—Modulus of elasticity of FPL structural flakeboard after exposure to 1-24 cycles of three different exposures.
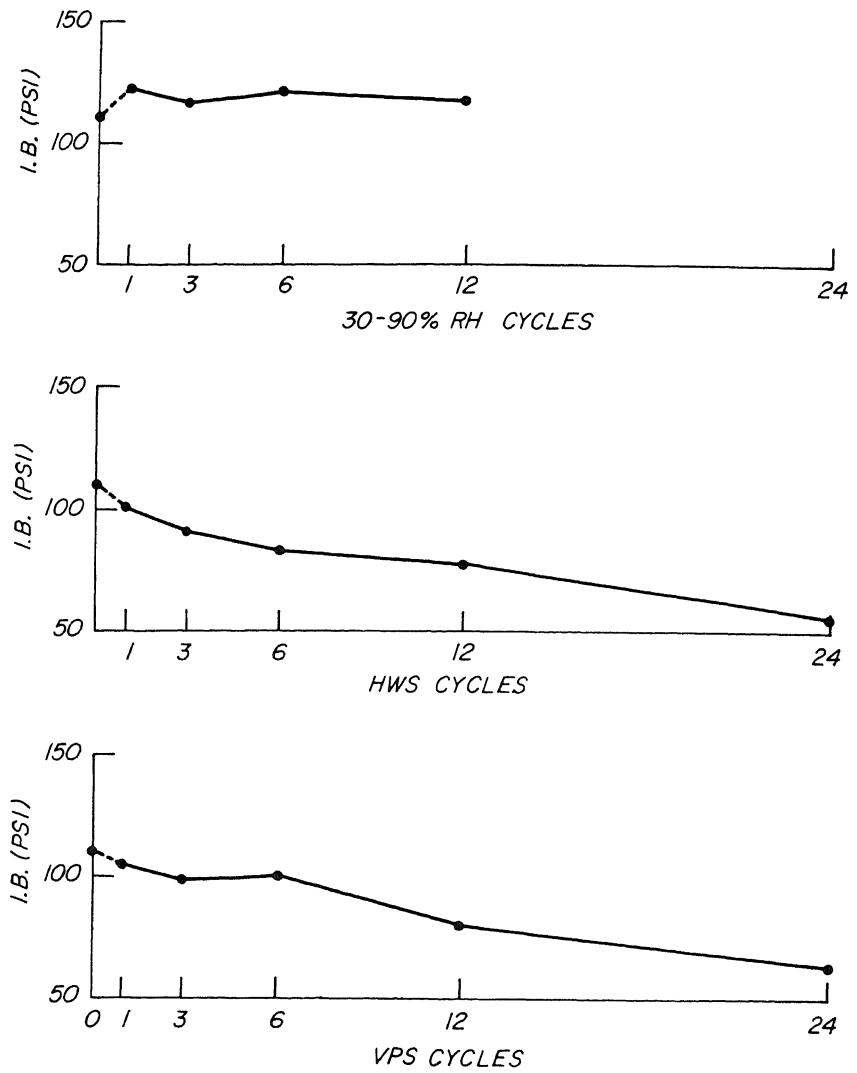
Figure 9.--Internal bond strength of FPL structural flakeboard after exposure to 1-24 cycles of three different exposures.

132

PLANT FACILITY CONSIDERATIONS FOR STRUCTURAL FLAKEBOARD MANUFACTURE

Peter Vajda
Columbia Engineering International, Ltd.
Vancouver, B.C., Canada

Introduction

In 1976, Columbia Engineering International, Ltd.
Eugene, Oregon, carried out an extensive study on
design criteria, equipment requirements, and
ital costs of structural flakeboard plants. The
dy was commissioned by the U.S.D.A. Forest
vice, Forest Products Laboratory (FPL) at
ison, Wisconsin. The raw material supply con-
ions and the product configuration were based on
research carried out by FPL in 1975-1976. This
er reports the results of the study by Columbia
discusses the considerations and judgments
d in arriving at a conceptual plant design
equipment selection.

The definition of a "structural flakeboard" or
physical properties required for a board product
be deemed "structural" are somewhat vague at
sent. What we do know is that, in a structural-
le product, we would like to optimize strength,
ffness, and dimensional stability (especially
ear expansion) properties and assure that these
perties are retained over a long period of time
under varying temperature and humidity condi-
ns. We also know that boards made from "flakes"
e basically a higher modulus of elasticity,
ulus of rupture, and lower linear expansion than
rds made from "random-type particles" such as
vings, sawdust, or hammermilled chips. Further-
e, strength retention under varying temperature
humidity conditions, or indeed exposure to
ther, requires the use of an exterior-type binder
h as phenolic resins, rather than the urea form-
ehyde resin used in the manufacture of interior-
le industrial particleboards. It is commonly
epted therefore, that structural-grade particle-
rd will have to be made with flakes (rather than
dom particles) and with an exterior-grade binder
enolic or other).

The only type of "structural flakeboard" manu-
tured commercially at the present is a product
ed "waferboard." "Wafers," or large, square,
her thick flakes, are used in its manufacture.
e waferboard plants are operating at present--
e in Canada (MacMillan Bloedel Ltd., Hudson Bay,
k. and Thunder Bay, Ont.; Great Lakes Paper,
nder Bay, Ont.; Weldwood, Longlac, Ont.; and
erboard Ltd., Timmons, Ont.) and one in the
ted States (Blandin Paper Company, Grand Rapids,
h.).

Another type of structural board is manufactured
the present, although not in commercial quan-
ies: "Oriented Strandwood" made by Potlatch
sts, Inc., Lewiston, Idaho, in a pilot plant.
latch does, however, manufacture a cross-
ented board in a commercial plant. It is used
the production of a plywood-like product having
twood veneer faces and the cross-oriented flake-
rd core. This product is marketed under the
e "Plystran."

All presently operating waferboard plants use
aspen roundwood for raw material and derive the
flakes or wafers by disc- or drum-type flakers.
The furnish for "Strandwood" consists of "strands,"
elongated flakes made from roundwood by a drum-
type Hombak flaker. The flakes for the "Plystran"
core are made by a ring-type flaker from softwood
"maxi-chips" (large, thick chips).

The process concepts, equipment selection, and
plant designs presented here are based on the expe-
rience gained in the design and engineering of four
of the abovementioned plants, and the experience
of the Canadian waferboard industry over the past
12 years. The author also drew on the experience
of the conventional interior-grade industrial
particleboard industry, especially as it is related
to the manufacture of industrial-grade particle-
boards from flakes--rather than from random part-
icles (sawdust and shavings)--both in North America
and in Europe.

Board Configuration & Raw Material Supply

The essential finding of the research at FPL in
Madison was that a board of structural properties
may be manufactured by using "semi-flakes," from
chips, in the core and "true flakes" from round-
wood, in the face layers. This finding is impor-
tant because, as mentioned earlier, all presently
operating waferboard plants use roundwood raw mate-
rial exclusively and because the ability to use
chips rather than roundwood--in at least part of
the raw material supply--can result in significant
savings. Some mill waste (slabs, edgings, etc.)
as well as forestry and logging waste may be con-
verted into chips or "maxi-chips" or "fingerlings"
and then transported in bulk to the plant at a
cost significantly lower than the harvesting and
transporting cost of roundwood. On the whole,
therefore, the ability to use chips rather than
roundwood, at least for part of the raw material
supply, would not only reduce delivered wood costs
but would also permit a more complete resource
utilization.

Although the terms such as "flakes," "true
flakes," and "maxi-chips" are used fairly commonly
in the industry and in research publications, they
are not always exact. Nor is there a consensus as
to the effect of flake type, size, and quality on
board properties and resin consumption. It is
therefore necessary and useful to briefly redefine
some of these terms.

The term "true flake" here describes flakes or
particles made from roundwood by disc- or drum-
type flakers. A true flake is a flake or particle
which has a rather well defined length, width, and
thickness, the thickness being much smaller than

length and width, and in which the grain of the wood is basically parallel with the broad flake surface (length or width). Only a disc- or drum-type flaker fed with roundwood is capable of producing true flakes with a reasonable degree of predictability.

A ring flaker fed with chips or "maxi-chips" will or may produce some "true flakes" but, on the whole, grain direction and flake size are not predictable. Only the thickness of the flake is reasonably well determined. For purposes here, these flakes are called "semi-flakes" or "chip flakes."

"Fingerlings" are chip-like chunks of wood in which the grain is parallel to the broad surface, as opposed to the pulp chip in which the grain runs at right angles to the broad faces. If fingerlings are fed to a ring flaker, probably a greater number of the resulting flakes will be "true flakes." Even in this case, however, the surface presented to the knife of a ring flaker is not predictable, nor are flake size or grain direction. For the purposes of this paper therefore, these too are called "semi-flakes."

As to the effect of flake type on board properties, it is a well established fact that the use of "true flakes" will result in optimum panel bending strength, stiffness, and linear expansion properties. "Semi-flakes," on the other hand, will give better internal bond properties. It is also indicated, although not proven, that the use of semi-flakes will result in improved horizontal shear properties. Horizontal shear has seldom been tested in industrial particleboards but is likely to gain increased attention in structural-grade panels.

True flakes in the face layers and semi-flakes in the core layers should give optimum modulus of rupture, modulus of elasticity, linear expansion properties, and internal bond and horizontal shear (especially if the face layers are pressed to a higher density than the core layer)--i.e., the optimum of such properties for a given species and at any given resin content. There is an important question, however, which must be answered for the sake of plant design and predictability of product performance: Are "semi-flakes" positively required for the core or are "true flakes" just as acceptable or possibly better in some respects?

For our purposes, as well as the conceptual plant design and plant costs prepared earlier for FPL, it is assumed that all the roundwood received by the plant will be flaked on disc or drum flakers, and the true flakes sent to the face layers. The core layers will be made from semi-flakes as produced by ring flakers from chips received in chip form by the plant. None of the plants are designed to chip roundwood at the plant site.

Plant Design Parameters

The raw material supply conditions set out for the plant design were:

1. 40 percent of the raw material demand in the form of tree-length logs (to produce true flakes for the face layers); 60 percent of the demand in the form of whole-tree or forestry-waste chips (semi-flakes by ring flaker for the core layer).

2. 40 percent of the demand in the form of true flakes resulting from a shaping-lathe operation (for face layer); 60 percent of the demand in whole-tree chips (semi-flakes for the core).

3. 100 percent of the demand in the form of flakes resulting from a shaping-lathe operation for both face and core layers. (this raw material supply alternative was to be applied only to the smallest-capacity plants as the potential volume of shaping-lathe flakes available at any given site was thought to be limited.)

The plants were to be designed for four basic output capacities:

37.5 MMSF 1/2-inch per annum (about 35,000 ovendry tons)

75 MMSF 1/2-inch per annum (about 70,000 ovendry tons)

112.5 MMSF 1/2-inch per annum (about 105,000 ovendry tons)

150 MMSF 1/2-inch per annum (about 140,000 ovendry tons)

A number of suitable press sizes were to be considered for each plant output capacity.

At the outset, FPL specified that wood waste and coal should be used as plant fuel, both for the boiler and for the dryers. Later, it was decided that because the use of coal would complicate fuel handling and burner design, the fuel of the plant would be limited to self-generated waste (bark, fines, and board trim), complemented by purchased hog fuel or hogged forestry waste, as required.

All plants were to be designed for northern as well as southern climates and the effect of climate on plant costs and operating costs was to be studied.

Plant Design Considerations

To deal with the great number of variables and to show their effect on plant and equipment configuration in a logical and easily comparable manner, the plant was broken down into appropriate sections, depending on the sensitivity of each section to the variables. The selected plant sections were considered along with the variable conditions directly affecting their design and equipment sizing.

Each plant section was then designed as a separate unit. The capital cost of each section was also estimated separately, complete with installation costs, concrete bases, pits, etc.

The complete plants were then built up by using the plant section combinations appropriate for each set of conditions. By this method it was possible to design and estimate 34 plants in an easily traceable manner by varying the combination of nine basic plant sections. This resulted in a plant design easily adaptable to any probable raw material input condition, climate variation, and basic panel size requirement.

134

Woodyard & Flaking

The configuration of the woodyard and flaking (WF) section depends largely on the raw material form input conditions. The sizing of the machinery depends on throughput or plant capacity. Climatic conditions have some influence, mainly in the size of thaw ponds (to condition the roundwood prior to flaking) and the need to house or leave in the open certain equipment components. For the sake of simplicity, the effect of climate was neglected in the assembling of these sections and was taken into account in the auxiliary and building sections of this study.

Three basic WF sections are provided to handle the three different types of raw material forms supplied to the plants:

- WF1 (and WF1a) for shaping-lathe flakes
- WF2 for tree-length (or shorter) logs
- WF3 for chips

The capacity of the WF1 and WF2 sections is designed for 40 percent of the input requirement of each plant size. The WF3 section is designed for 60 percent of the raw material input requirements. In the case of the smallest plant (37.5-MMSF per annum), a WF1a section is provided to handle 100 percent of the raw material in the form of shaping-lathe flakes.

The design flow rates are shown in Table 1A and the equipment details in Table 1B in Appendix A. The total installed cost details at each designated plant capacity are shown in Tables 1C, 1D, and 1E.

This simple section consists of a truck dump, a storage bin, and a dryer metering bin with the necessary conveying equipment. The assumption here is that the lathe flakes will be made by shaping-lathe operations located in the vicinity of the board plant and will be delivered by truck.

(This is a somewhat dubious assumption. To supply about 30,000 ovendry tons per annum of lathe flakes (about 40 percent of the supply requirement of the 75-MMSF plant, and about 100 percent of the supply requirement of the 37.5-MMSF plant), about 40 MMbf of lumber would have to be produced by shaping-lathe operations in the vicinity (at 0.7 to 0.8 ovendry tons of flakes per Mbf). This is a respectable lumber production and it is questionable whether such a large concentration of shaping-lathe operations is indeed practically achievable in the vicinity of any given plant.)

About 12 hours of flake storage is provided in a Miller Hofft horizontal H-type bin with travelling screw feed. This amount of storage may not be sufficient. Any further storage capacity would not be practical and economical in a self-feeding type of bin and would have to be provided in the form of an open or covered storage pile, fed by stacking conveyors, the outfeed accomplished by front end loaders. Vertical silos or bins are not recommended; the green flakes have a much greater tendency to bridge and are more difficult to feed than either chips or shavings or even hog fuel.

The flow rates and equipment breakdown cover the basic requirements of the plant section handling shaping-lathe flakes. This section may have to undergo considerable modification depending on the specific raw material supply conditions for any given plant location. Design flow rates are shown in Table 2A. The equipment breakdown and costs are shown in Table 2B and the installed section costs in Tables 2C and 2D.

According to the experience of the existing waferboard plants, it is necessary to thaw the logs before flaking in the wintertime and in northern plant locations. In these plants, the heating, soaking, or preconditioning of the logs has resulted in better flaking performance and lower fines generation (even in the summertime) and has therefore been accepted as common practice in the waferboard plants. The conditioning of the logs is thought to be especially important in the case of hardwoods.

Because the flakes derived from the logs will end up in the face layers of the board, it was thought to be necessary to debark the logs prior to flaking. This, again, is common practice in waferboard plants. Because frozen logs cause a great deal of trouble in the debarking operations as well, a soaking or thawing pond, designed to thaw the outer layers of the logs prior to debarking, has proved to be beneficial. Such a pre-thaw pond would not be required in a southern plant location. In its stead, however, a log deck would be required which would cost about the same amount to install and operate as a pre-thaw pond.

The logs are slashed to 8 feet long and debarked. If most logs are relatively straight, it would appear to be beneficial to slash the logs after barking; for relatively crooked hardwood logs, before barking.

The 8-foot-long logs are then fed into hot ponds. Pond size and storage time required in them depends largely on climatic conditions, but also on average log diameter. In cold northern climates, 8 to 10 hours storage in these hot-water ponds is required for thawing out 8- to 10-inch-diameter logs. The same logs are kept in the pond for conditioning for between 2 to 4 hours during the summertime.

Most waferboard plants flake logs on a disc-type flaker. Disc flakers produce a more consistent flake than do drum flakers. Because the maximum length to be fed to a disc flaker is 24 inches, and disc flakers have a chain-type side feed, logs would have to be slashed to a very accurate 2-foot length. This results in a substantial amount of waste. The feeding of such short logs to a disc flaker is difficult to accomplish without constant operator supervision.

The capacity of a standard 4-foot-wide drum flaker is about 30,000 ovendry tons per hour, far in excess of the capacity requirements of the smaller plants. A smaller flaker would mean increased handling and labor costs and is therefore not considered to be economical. As a result, the same 4-foot-wide drum flaker was used for all plant output capacities. For the largest 150-MMSF plant, the capacity of one flaker may be somewhat marginal, and room should be provided for the future addition of the second flaker should it be required.

135

A 4- to 8-hour storage capacity wet flake bin is provided after the flaker to even out the flow within the flaker and the dryer. Very few of the waferboard plants have such a wet flake bin and they experience some trouble in coordinating flaker and dryer operations. Flakes are difficult to handle in the bin. Here again, a Miller Hofft H-type bin is provided with the condition that the bin should be kept long and low in order to obtain the least troublesome outfeed conditions. As the large bin is not thought to feed at a sufficiently accurate rate to the dryer, an additional metering bin is inserted between the wet flake bin and the dryer operation.

All the waste generated by this tree-length log handling, slashing, and flaking section (bark, slasher sawdust) is sent to the fuel preparation section which will be described later.

The design flow rates are shown in Table 3A, equipment details and costs in Table 3B, and installed section costs in Tables 3C and 3D.

The chips are delivered to the plant by truck and are received by a truck dump and bin. They are delivered either to open storage by a radial stacker (and fed back into the stream through a reclaim hopper) or to an 8-hour chip storage bin (a Miller Hofft or similar-type unit with the outfeed consisting of a travelling screw and belt conveyor). The bin delivers the chips to a chip screen--the accepts being forwarded to a feed bin to the ring flaker and the fines going to fuel.

One ring flaker was used in the smallest plant unit. The larger plants have an appropriate number of additional ring flakers. From the ring flaker, the flakes are delivered to the dryers by a pneumatic conveyor system.

This chip handling and flaking section is quite similar to the ones used in conventional industrial-grade particleboard plants.

Drying & Blending

The nature and the size of the drying and blending section is affected only by flow rate or plant throughput. The face flakes, however derived, are dried and blended in one stream and the core flakes, whatever their source, through another stream. By providing some cross conveyors between the two flow streams, before and/or after drying, 60 percent of the furnish could be sent to the face side and 40 percent to the core side or vice versa. It would also be feasible to feed some true flakes to the core side or some chip flakes to the face side, if necessary.

The flow rates for each plant and for each flow stream are shown in the equipment breakdown detail in Tables 4B and 4C. The installed costs of these units are shown in Tables 4D, 4E, and 4F.

Rotating-drum, three-pass, air-suspension dryers have been selected for the plants (Heil-type, also MEC, Guaranty Performance), equipped with wood-dust or dry-wood-particle burners (such as Energex, Romec, etc.). The drying of large flakes using any type of dryer fired with wood is a somewhat unexplored field and is in need of improvement. This type of dryer and fuel system was selected because it is, to some extent, proven in waferboard plant operations.

It is desirable to keep input temperatures low to reduce fire hazard and emission (blue haze). In a Heil-type dryer, this means lower output at a given drum size or higher air volume. Increased air volume results in higher horse power requirements. Indications are that a larger drum size for a given output, coupled with relatively lower air volumes and longer retention time, would permit better drying efficiency at lower input temperatures when using large flakes as compared to smaller particles. This, however, is not entirely proven.

The dryers selected for this plant are expected to perform at an input temperature of 700°F to 800°F maximum and an output temperature of 190°F or slightly less, although lower input temperatures would be desirable.

Alternatives are available in the burning of wood fuel. A separate wood burning box or oven--possibly of the fluidized bed type, which would accept dry as well as green fuel--could serve as the main or only burning unit of the plant. The stack gases from this burning box would then be distributed to the dryers as well as to the boiler. This system has been proven by one particleboard plant and is being installed in another. Proper distribution of the stack gas and temperature control in the individual dryers is likely to be the problem area.

It is possible to feed all the fuel to a large, high-pressure boiler and heat the air to the dryers by steam-air heat exchangers. This has been proven by a number of particleboard plants using dry shavings as raw material, and gives low input temperatures and a minimum of fire hazard and blue-haze-type emission. For green flakes, however, it is fuel inefficient and requires high air volumes and, therefore, increased power on the fan.

The makers of stationary steam-heated dryers (such as Pondorff and Schilde in Germany) claim that these are more suitable and efficient for drying large flakes. These units are expensive to purchase for a given output capacity, their fuel efficiency questionable, and their flexibility as to output capacity very limited (Heil-type dryers can always be "pushed" by increasing the input temperature). Some claim that these units cause less flake breakage than the Heil-type, though the rotating rakes should and do churn the flakes more and for a longer time than the tumbling action in a rotating drum. Horsepower requirements for the stationary units are lower.

The most objectionable feature of these stationary units is that, due to the long retention time required, a great amount of flakes is in the vessel at any given time. Fines tend to accumulate and are not exhausted. Any fire would be difficult to extinguish.

After drying, the flakes are conveyed to screens where the fines are rejected and sent to fuel. Accepted flakes are sent to the face and core surge and metering bins respectively which, in turn, feed the weighing and blending operation.

All the waferboard plants use slowly rotating large drum-type blenders as the small, high-speed blenders commonly used have proven to cause excessive flake breakage. The resin system provided for the plants foresees the use of liquid phenol resins and either emulsified or molten wax.

One further note: To minimize flake breakage and fines generation, mechanical conveyors--preferably covered belts--are recommended. Air systems are to be avoided wherever possible.

Forming, Pressing, & Board-Trimming

This discussion assumes a standard caul-type unit commonly used in the particleboard industry. A caulless system does not appear to be feasible in the case of structural board as the phenolic resin has insufficient tack or "green strength" for holding a flake-mat together prior to pressing. Forming and handling the mat on screens (such as Flexoplan or similar) does have merit for the larger plants and will be discussed later.

The press sizes considered for the various plant output capacities are shown in Table 5A. The equipment cost breakdown is shown in Tables 5B and 5C. The installed costs of the various forming and pressing sections are shown in Tables 5D, 5E, 5F, and 5G.

For the 37.5-MMSF-capacity plants, 4- by 8-foot by 24-opening and 4- by 16-foot by 12-opening press configurations were provided. The continuous press was also considered, but since 1976, little progress has been made in perfecting the various continuous presses proposed then. It was found that the longer cycles required for phenolic-bonded board would result in excessive press length. The mechanical problems which accompany such press length have not been solved to date. As a result, the continuous press cannot now be considered a serious contender for this application.

For the 75-MMSF plant, a 4- by 16-foot by 24-opening press configuration--as used by five of the existing waferboard plants--was chosen. For the 112.5-MMSF plant, a 4- by 24-foot by 24-opening and an 8- by 24-foot by 12-opening press unit were selected. The 4-foot-wide unit requires loading times close to the minimums practically achievable (about 10 seconds per board at a 4-minute press cycle). This may justify an 8-foot-wide press despite its higher first cost.

The largest output capacity (175-MMSF) cannot be achieved on a 4-foot-wide unit. In this case, an 8- by 24-foot 16-opening unit was the only alternative considered.

The larger panel and press format, especially larger width, does have the advantage of lower speeds at any given output as well as somewhat lower board trim losses. However, its first cost (purchase and installation cost) is higher, as is the cost of a wider former, mat handling, board trimming, and stacking equipment (4- by 8-foot by 24 openings vs. 4- by 16-foot by 12 openings, or 4- by 24-foot by 24 openings vs 8- by 24-foot by 12 openings).

Savings in terms of trim losses seldom justifies the incremental investment in larger presses. The larger press format must therefore be justified in terms of reduced forming and loading speeds and, more importantly, the sales advantage of a larger panel. Forming speed alone is not objectionable. The time available to load one board into the loader (plus elevating time) is fairly

well limited to 10 seconds, especially in the case of a loose flake mat.

For the 4-foot-wide lines, the conventional caul systems are the most practical and proven in operations. Cauls 8 feet wide are difficult to handle and are subject to expansion, contraction, and warping unless made from expensive alloys. In the case of the 8-foot-wide presses, therefore, the use of a screen (such as the Schenck Flexoplan system used extensively in Europe) instead of a caul does have real merit.

There is an additional reason for considering a screen or Flexoplan system. When waferboard is used as roof deck (one of its most common applications), it is much more slippery than plywood. By manually placing a screen on top of the mat, a screen-back-type board, such as wet-process hardboard, is produced, giving a skid-proof or skid-resistant surface.

Placing a screen on the caul is not considered to be a practical solution because it causes problems in the board-caul separating station. A Flexoplan-like system provides a screen and overcomes this board-caul separation problem. It will also provide the breathing of the board in the press and moisture or steam escape. In view of all these factors, the screen mat handling system has real merit in the larger press sizes and at the large plant output capacities.

The board trim saw is "on-line,"--directly connected to the press line. An emergency stacker feeder is provided ahead of the saw so that boards may be unloaded and re-fed to the saw in case of changes or other operating problems in the saw unit. The boards are forwarded to either a stacker or a grading line.

No orientation equipment is provided in this estimate.

No sander is provided as none of the existing waferboard plants have a sander and this "plant" is designed to manufacture a sheathing-grade panel.

All the presses are heated by steam--a satisfactory method of heating presses in North America. This, by the way, is considered the most economical solution since steam is required for plant and hot pond heating as well. A hot-water or hot-oil heating system may also be considered.

Boiler & Fuel Preparation

Table 6A shows the steam requirements for each plant and the basis for determining the required boiler capacity. Tables 6B, 6C, and 6D show the cost estimates for purchasing and erecting various size boilers, including the necessary fuel preparation and fuel drying facilities.

The green fuel (bark, slasher sawdust, green chip fines, and purchased hogged fuel) is dried in a dryer fueled by the stack gases of the boiler. The dried fuel is mixed with dry fines rejected by the screening operation after furnish drying and the hogged trim waste from the trim saw. This combined wood fuel is hammermilled to the appropriate size and sent to a metering bin which portions out the fuel to the boiler and to the burner units of the dryers.

This fuel preparation system represents one practical and feasible solution. As mentioned earlier, an alternate system which has been installed and reasonably well proven in two plants is to put all the fuel in a specially designed burner (possibly fluidized bed). Here, dry and green fuel can be mixed and the stack gases of the boiler could also be fed into this burner unit. The hot gases generated from this burner can then be distributed to the boiler and various dryers.

Auxiliary Equipment

Tables 7A and 7B show the breakdown of auxiliary equipment provided for each plant. The tables are made separately for southern and northern locations and the differences in equipment sizing for these two cases are shown.

Buildings, Structures, & Site Development

Building and site development requirements had to be estimated separately for each plant configuration and each location. Due to space limitations, the details of these estimates are not given here. They are, however, attached to the composite and complete plant estimate samples in Appendix A.

Complete Plant Configurations

The complete plant configurations were constructed by varying the combination of plant sections appropriate to the designated plant capacity, raw material input, climatic conditions, and selected panel or press size.

Three examples of the 34 plant alternatives studied are shown for constructing a total plant configuration from the appropriate plant sections:

1. Capacity: 37.5 MMSF 1/2" per
                                     annum
    Raw Material Conditions: 100% lathe flakes
    Press Configuration: 4' x 8' x 24 openings
    Location: Southern
    Plant Section Components:
        Woodyard & Flaking   WF1a (Tables 1B & 1C)
        Drying & Blending   DB1 (Tables 4B & 4D)
        Forming & Pressing   (Tables 5B & 5D)
        Auxiliaries   (Table 7A)
        Boiler & Fuel
          Preparation   10,000 lb/h, 300 psig
                             (Table 6B)

The capital cost summary for this plant is in Table 8A and the building and site preparation costs in Table 8B (4- by 8-foot by 24-opening press configuration).

2. Capacity: 75 MMSF 1/2" per annum
    Raw Material Conditions: 40% lathe flakes; 60%
                             chips
    Press Configuration: 4' x 16' x 24 openings
    Location: Northern
    Plant Section Components:
        Woodyard & Flaking   WF1 + WF3 (Tables 1B
                             & 1C (75 MMSF) and
                             Tables 3B & 3C (75
                             MMSF))
        Drying & Blending   DB2 (Tables 4C & 4E
                             (75 MMSF))
        Forming & Pressing   (Tables 5B & 5E)
        Auxiliaries   (Table 7B)
        Boiler & Fuel
          Preparation   25,000 lb/h, 300 psig
                             (Table 6C)

The capital cost summary is shown in Table 9A, and the building and site preparation cost details in Table 9B.

3. Capacity: 112.5 MMSF 1/2" per
                                     annum
    Raw Material Conditions: 40% tree-length logs;
                             60% chips
    Press Configuration: 8' x 24' x 12 openings
    Plant Section Components:
        Woodyard & Flaking   WF2 (Tables 2B & 2D
                             (112.5 MMSF))
                             WF3 (Tables 3B & 3D
                             (112.5 MMSF))
        Drying & Blending   DB2 (Tables 4C & 4E
                             (112.5 MMSF))
        Forming & Pressing   (Tables 5C & 5F)
        Auxiliaries   (Table 7B)
        Boiler & Fuel
          Preparation   45,000 lb/h (Table 6D)

The capital cost summary is shown in Table 10A and the building and site preparation cost details in Table 10B. A summary of all the plant capital costs is given in Table 11A. This summary is also shown on a per unit cost basis ($ per MSF per annum) in Table 11B.

Validity of Cost Estimates

The cost estimates were prepared in 1976 and were thought to be accurate within ± 5 percent, assuming average site conditions, equipment standards customary in the board or wood products industry (not pulp mill standards), the use of simple standard prefabricated steel or wood buildings (slab on grade) as well as normal and sensible purchasing and construction procedures.

Inflation should have resulted in a 10 to 15 percent increase in these costs since that time. Due to sharply reduced equipment sales and plant construction activity in the board industry over the past 3 years however, equipment costs, on the whole, have remained fairly stable. Hourly installation labor costs have increased but not beyond the labor productivity variations assumed and taken into account for the various locations and regions. As a result, the cost estimates should still be valid for 1978 within a probable accuracy of minus 0 percent and plus 10 percent, given the assumptions noted above.

eyond the third quarter of 1978 however, it
d be good to review costs and the inflationary
ds projected at that time for the plant con-
ction period.

Summary Comments

he foregoing sectionalized plant design concept
hought to be adaptable to a great number of
aterial input conditions, plant capacity and
s size variations, and climatic conditions at
ering locations. The plant flow and equipment
igurations of a structural board plant do not
er greatly from those of a conventional
cleboard plant, especially plants utilizing
dwood and/or chips as raw material.

he waferboard industry has shown that the exist-
echnology of structural board manufacture is
ational. Both the technology and the marketing
ructural board however is only at the initial
e and is in need of further research, develop-
, and general improvement. The most important
in this regard may be summarized:

Basic research is necessary to positively
determine the effects of flake type and size,
flake quality, and species, on board proper-
ties. The plant operator should have infor-
mation as to the flexibility possible in raw
material procurement and processing alter-
natives while still maintaining predictability
of product properties.

Marketing research aimed at determining the
value of product appearance to marketability
is required. The need to debark the round-
wood for waferboard is justified mainly in
terms of product appearance. If the main
mass market for the product is in structural
sheathing-grade applications, appearance
would appear to be of little value and the
need to debark eliminated. This would mean
lower operating costs and a greater flexi-
bility in raw material supply. It is to be
noted here that European flakeboard plants
seldom debark roundwood.

All waferboard plants use a powdered phenolic
resin which is not only expensive but is also
difficult and costly to handle. Potlatch
uses a liquid phenol. A greater quantity of
resin solids are required in liquid form than
with dry powder (5 to 6 percent solids in
liquid form vs 2.5 to 3 percent in powder)
but unit resin costs are similar because
liquid phenolic per pound of solids is half
the purchase price of phenolic powder. In
addition, liquid is a great deal easier to
handle. The blending of liquid phenol to
relatively large flakes, strands, or wafers,
however, does require further development
work as does the blender type suitable for
this operation.

Further research is indicated with regard to
alternative exterior resins. One alternative,
mentioned frequently today, is isocyanate.
The other is the extender made with dried and
powdered coniferous foliage developed by the
Western Forest Products Laboratory (Environ-
ment Canada) in Vancouver, B. C.

- Flake orientation certainly appears to pre-
  sent an inexpensive way to more than double
  board bending strength and stiffness as well
  as to improve dimensional stability. Improved
  properties at the same product price would
  open up new market applications as well as
  enhance the competitive position in all
  markets.

- The manufacture of structural board on a
  screen-type mat handling system, rather than
  cauls, offers potential advantages. Further
  research and plant experience is required to
  confirm this potential.

At the present, and in my judgment, structural
flakeboard offers the greatest growth potential
in the reconstituted wood panel industry. I hope
that my remarks will encourage the necessary
research and development work on the part of
equipment suppliers, as well as research institu-
tions and chemical companies, and the wood panel
manufacturing industry itself.

OVERVIEW OF STRUCTURAL FLAKEBOARD PRODUCTION COSTS

George B. Harpole
Economist
USDA Forest Service
Madison, Wisconsin

Abstract

On the basis of experimental results
with three-layer board compositions and
estimates of investment and operating
costs, production costs were computed
using discounted cash flow techniques for
16 possible structural flakeboard manu-
facturing sites. The production costs
computed include taxes, profits, and
other selling and manufacturing costs.
After computing production costs, ex-
cluding wood costs, then computing the
coefficient for converting wood cost per
ovendry ton to production costs including
associated increases in selling, tax,
and profit costs, total production costs
can be expressed in "a = bX" equation
form. Feasibility can then be assessed
by matching expected production costs,
including independent assumptions about
wood costs, with likely f.o.b. mill
market values for product output.

Introduction

Techniques for producing structural
flakeboard products from hardwood and
softwood forest residues have been deter-
mined. Unsolved, however, is the ques-
tion of commercial feasibility. Pre-
liminary analyses may be used solely to
explore economic possibilities of new
processes or products. Or, preliminary
analyses may be used to help establish
target investment costs for architectural-
engineering purposes. Even after
acceptable cost estimates and market
forecasts are developed a number of
manufacturing-marketing strategy combina-
tions may need to be assessed before a
final combination is found. For these
reasons, the purpose of this paper is
two-fold: 1) To describe the tech-
niques used and the results of analysis
of structural flakeboard manufacture, and
 2) To announce the availability of the
computer programs used for the economic
analysis of structural flakeboard manu-
facture.

The two computer programs used to
simulate structural flakeboard manufacture
are named PARVCOST and CFA. Both pro-
grams, written in FORTRAN for use on
Univac 1108 and 1110 systems, may be
readily adapted to economic assessments
of other wood products manufacturing
processes.

PARVCOST Computer Program

PARVCOST is a mathematical model of
wood, chemical, and energy flows within
an operating flakeboard plant (Fig. 1)(2).
PARVCOST computes physical requirements
and costs of wood, chemicals, and energy
per unit of finished panel output as well
as finished panel weight statistics and
profit contribution (unit price minus
unit variable cost) from the market value
of product output. PARVCOST also com-
putes the sensitivity of finished product
costs to changes in unit costs of energy
and raw materials.

PARVCOST may be used to compute the
unit variable costs for discounted cash
flow analyses, or may be used directly to
gage the relative feasibility of manu-
facturing structural flakeboard between
sites where raw materials, energy, and
product outputs have different values
but investment and operating costs are
equal.

CFA Computer Program

The CFA program is designed to
simulate and analyze investments, costs,
and revenue cash flows of manufacturing
ventures for their useful or economic
life (to 20 yr)(1). Discounted cash flow
analysis represents an analytical tech-
nique commonly used to generate many
types of time-valued economic criteria.
Truly comparable investment opportunities
represent identical functional feasi-
bilities, economic lives, risks, and
financial requirements. When these
conditions exist, the profit contribution
computed by PARVCOST may be used as a
valid criterion for assessing processing
or investment alternatives. Where these
conditions do not exist, the appropriate
use of discounted cash flow methods will
yield more useful criteria.

The CFA program is designed to com-
pute after-tax time values of investment
and operating cash flows for manufacturing
ventures in terms of 1) present value
of the investment, 2) internal or com-
posite rate of return, 3) total unit cost
of production, and 4) maximum investment
that can be made under prescribed
operating costs, revenues, and rate of
return. Additionally, the CFA program
is written so standardized time, invest-
ment, and rate-of-return (ROR) values can
be used, and computations of the least
certain elements of a manufacturing
venture can be computed and used as
economic criteria, such as the total cost

of production that includes tax costs and prescribed after-tax profit.

The CFA program computes both an internal ROR (IRR) and a composite ROR. The composite ROR is the rate of equity investment earning when specifying a borrowing interest rate, and short-term reinvestment for cash surplus. The IRR used for the following analyses, represents the single interest-rate situation of typical interest to a corporation capable of fully financing a new investment venture from internal resources. The IRR is the interest earnings realized as an after-tax profit with the return of principle for the financing requirements of a venture. The IRR can also be defined as the rate of interest required to discount the stream of annual net cash flows to a present value of zero.

Economic Analysis

Costs to produce flakeboard products from forest residues at 16 sites in the United States were estimated and compared with the likely market value of product output. For this study a consultant (Columbia Eng, Intl, Inc,, Eugene, Ore.) determined the equipment requirements and costs to construct operable structural flakeboard facilities and to provide estimates of operating requirements (Appendices A, B, and C). From this information, operating costs were estimated and costs of panel production were computed for nine northern and seven southern sites in the United States (Fig. 2, and Appendix D).

Unit costs of production include taxes, selling costs, and profit, in addition to the costs of manufacture. These costs are also the product selling prices, f.o.b. mill, required to yield a 15 percent internal rate of return (IRR) from discounted cash-flow analysis. Production costs are expressed in dollars per 1,000 square feet of product output on a 1/2-inch thickness basis (MSF, 1/2 inch).

Investment Requirements

The costs (1976 basis) of constructing operable structural flakeboard facilities were estimated for two climates: temperate (South) and cold (North). Facilities ranged in rated output capacities from 37.5 MMSF, 1/2-inch, to 150 MMSF, 1/2-inch, per year. The smallest facility, 37.5 MMSF per year, was evaluated for three types of wood supplies: 1) wood flakes, as from a shaping lathe headrig, 2) mixtures of wood flakes and chips, and 3) mixtures of logs and chips. At least 30 percent of the structural flakeboard furnish must be of high-quality flake, such as produced from roundwood using a disk flaker, or shaping lathe headrig to produce the high-strength faces required for structural

flakeboard. Facilities sized from 75 MMSF, 1/2-inch, to 150 MMSF, 1/2-inch, are evaluated, assuming either mixtures of flakes and chips or of logs and chips.

Two investment requirements are considered: 1) investment to establish physical facilities for structural flakeboard manufacture, and 2) working capital to cover the costs of operating inventories of raw materials, goods in process, and accounts receivable (Table 1). Average facilities costs ranged from a low of $8,384,000 to a high of $27,292,000. Working capital requirements were computed to accommodate 2 months of annual operating costs, less selling expense, for facilities supplied with chips or flakes or both; and, for 3 months for facilities supplied with logs and chips.

Production Costs

Discounted cash-flow analyses were used to compute production costs. Computer output pertaining to a 112.5 MMSF, 1/2 inch, per year facility utilizing flakes and chips at an Arcata, Calif., site is used as an example (Table 2). Computations were made to determine the unit selling price required to cover all costs and yield an after-tax IRR of 15 percent. The computed prices which represent full production costs for structural flakeboard included selling expense, taxes, and profit. Raw material costs were computed using the PARVCOST program, which considers wood, chemical and energy requirements and costs (Tables 3 and 4). However, because of the variability and uncertainty of wood costs, production costs were first computed that exclude wood costs. Wood costs were considered in a secondary step of the discounted cash flow analyses and will be discussed.

Labor costs for skilled and unskilled labor were increased by 30 percent to account for costs of fringe benefits. These were estimated separately for each site (Appendix C). As for other costs and revenues, labor costs were increased 5 percent per year to establish the annual cash flows used for discounted cash-flow analyses. Manning for each facility was assumed two-thirds of full requirements during the first year of operation and at full manning (3 shifts, 325 days per year) in succeeding years. Production was assumed to be 44.6 percent of capacity in the first year; 84.2 percent, in the second year, and full capacity, in succeeding years.

Administrative overhead costs include building heat, water, electricity, administrative salaries, and miscellaneous supplies and services. Factory overhead costs (computed as 8.5 percent of

facilities' costs, excluding land cost, for the first year) cover costs for maintenance labor (6 percent), process supplies (0.5 percent), local taxes (1 percent), and insurance (1 percent). Other cost factors used in the analysis include an investment tax credit (equal to 10 percent of the cost of processing equipment), depreciation (Federal Internal Revenue Service depreciation guidelines), and state and Federal revenue taxes.

For simplicity, production costs are expressed in terms of 1976 unit sales prices (Table 5). The components of costs represent the average distribution of revenues to costs over the 10 years of discounted cash-flow analysis.

Depending on the site and the size of a facility, estimated production costs, excluding wood costs, range from about $110 to $230/MSF, 1/2 inch (Fig. 3, Appendix D).

Sensitivity of Production Costs

Economics of large-scale operations represent gains primarily in processing labor productivity and increased efficiency of administrative and maintenance requirements. Efficiencies gained by using large press sizes in the large facilities reduce trim losses, and glue, wax, and energy requirements. The gain in efficiency of the largest press size considered (8- by 24-foot) over the smallest (4- by 8-foot) is estimated to represent cost savings from $2 to $3/MSF, 1/2 inch. Efficiency of resin and wax use range from 88.6 percent for the 4- by 8-foot press to 94.7 percent for the 8- by 24-foot press. Efficiency of wood use for both softwoods and hardwoods ranges from about 80.0 percent for the 4- by 8-foot press to about 82.5 percent for the 8- by 24-foot press.

Estimated costs for 75 MMSF, 1/2-inch facilities (annual rated capacity, 3 shifts, 325 days per year) are about 40 percent greater than the costs for 37.5 MMSF, 1/2-inch facilities, and yield production costs about 23 percent less. Costs for 112.5 MMSF, 1/2-inch facilities are about 28 percent greater than those for 75 MMSF, 1/2-inch facilities, and production costs are about 10 percent less. A 150.0 MMSF, 1/2-inch facility costs about 33 percent more than a 112.5 MMSF, 1/2-inch facility but only reduces production costs about 2 percent.

Wood Costs

Wood costs were analyzed separately from other production costs. An average of about 1.06 ovendry tons of softwood raw material is needed to produce 1 MSF, 1/2-inch-thick panel (gross shipping weight of about 1,900 pounds MSF, 1/2-inch, at 7 percent moisture content (MC). For hardwoods, about 1.18 ovendry tons of wood are needed to produce 1 MSF, 1/2-inch-thick panel (gross shipping weight of about 2,200 pounds/MSF, 1/2-inch, at 7 percent MC).

Wood cost for 1/2-inch panel, per MSF, is then about 6 percent more than the cost of wood raw materials per ovendry ton for softwoods, and about 18 percent more than for hardwoods. To translate wood cost into production costs, selling expense and increases in profits and taxes to cover financing costs (15 percent) for increases in working capital requirements were added to the cost of the wood (Table 5). The production cost for wood per MSF, 1/2-inch, therefore ranges from 1.17 to 1.43 times that of wood raw materials per ovendry ton. (The costs depend on efficiency of facility and average density of wood raw materials.)

Because concentrations of forest residue-type materials and their size and shape, and distance from their point of use, are highly variable, costs of harvesting and transporting these materials are also highly variable. Estimates of wood costs prepared for the 16 sites indicate wood costs may range from $13 to $41 per ovendry ton.

Production Costs--Inclusive of Wood Cost

After computing costs of structural flakeboard production, excluding wood costs, and after computing the coefficient for converting wood cost per ovendry ton to production costs that include additional selling expense, taxes, profit and costs, total production costs can be expressed in equation form:

$$PC = a + bX$$

where,

PC is production cost ($/MSF, 1/2-inch); a, production cost excluding wood cost ($/MSF, 1/2 inch); and b, coefficient of wood cost per ovendry ton); X for calculating wood cost per MSF, 1/2 inch.

Production costs, including wood cost, can then be readily calculated as a function of highly variable wood costs necessarily considered for computing total production costs for structural flakeboard (Appendix D).

In the discounted cash flow analyses, all costs and unit prices were increased 5 percent per year to approximate annual increases in real costs and prices from the 1976 base year. To the extent this assumption reflects the trend of real costs and prices, the production costs expressed in this paper may be suitably adjusted to subsequent years by multiplying the 1976 base production costs (including wood cost) by annual adjustment factors = $(1.05)^n$ = the number of years production costs are to be adjusted forward. That is, to adjust production costs to a 1977 basis a factor of 1.05 should be used; to adjust production costs to a 1978 basis, a factor of 1.1025 should be used; and so forth.

Assessment of Feasibility

Preliminary assessments of commercial feasibility can be made by matching expected production costs of structural flakeboard against likely f.o.b. mill value of product

utput (Fig. 4). For example, the 112.5 MSF, 1/2-inch, per year facility utilizing lakes and chips at an Arcata, Calif., site ad estimates of total production costs, ncluding wood costs, ranging from about 15/MSF, 1/2 inch, for wood costs from $30/ SF to $33 per ovendry ton. The market alue, f.o.b. mill, for panel output was stimated (1976) to be about $167/MSF, /2 inch--subject to trade discounts of , 3, and 2 percent.

The most elusive elements of economic nalysis are wood costs, f.o.b. mill product alue, and selling expense allowances. For hese reasons, the relationship of full pro- uction cost could be readily calculated nd used for assessing manufacturing feasi- ility. However, selling expenses and rade discounting practices vary consider- bly, as indicated by the many wood products rice report publications. Traditional unctional discount structures for panel roducts have historically represented a 5, , and 2 percent discount structure, with he 5 percent typically conceded for the ffice wholesaler/broker function, the percent conceded for the additional ervice function of the stocking whole- aler, and the 2 percent as a cash discount or prompt payment of invoices (each dis- ount on the net invoice amount after educting freight). As mentioned, however, arketing practices vary considerably. For his reason, production costs have been omputed for three different assumptions elated to selling expense allowances:
. Low selling expense allowance which ssumes a 2 percent cash discount and annual roduct promotional costs, for the first years of operation, equal to $.50/MSF, /2-inch, of the rated annual output of the acility considered.
. Average selling expense allowance which ssumes a 2 percent cash discount and 5 per- ent for miscellaneous product promotional nd selling expenses.
. High selling expense allowance which ssumes the 5, 3, and 2 percent discounting tructure summarized above.
orresponding "a" and "b" values for pro- uction costs excluding wood costs (a) and he the coefficient for wood cost per oven- ry ton (b) are given in Appendix D for ach level of selling expense allowance ssumed. In the Arcata, Calif., example, a igh selling allowance of 5, 3, and 2 percent s assumed.

Alhtough some structural flakeboard ight be sold for specialty use as siding nd decorative panel use, the primary pportunity is probably for marketing com- odity grades of structural sheathing. Of ese products, CDX, 1/2-inch-thick plywood is e most predominant product in use. For tructural flakeboard products to compete the commodity sheathing markets, they ll probably have to be sold at or below revailing market costs for comparable ply- od sheathing materials. The market value, o.b. Arcata, Calif., is based on the verage market price of CEX, 1/2-inch-thick ywood sheathing f.o.b. Los Angeles, less

the higher cost of structural flakeboard. At most, the market value of structural flakeboard might cover a maximum wood cost of about $44 per ovendry ton.

Commercial feasibility can also be assessed by matching likely wood supply costs to the maximum wood costs that could be covered by estimated mill market price for panel output. These values can be calculated by subtracting the production costs, excluding wood cost, from the f.o.b. mill market value for panel output and dividing the remainder by the coefficient of wood cost per ovendry ton to yield a maximum supportable wood cost per ovendry ton.

Other aspects of commercial feasibility exist in addition to the analyses presented in this paper. Additional analyses might consider proprietary and intangible aspects that may influence feasibility. It is also possible that by modifying a largely depreciated particleboard facility to produce structural flakeboard, investment and production costs may be greatly reduced.

Summary and Conclusions

Forest Service research has shown structural flakeboard products can be produced from hardwood and softwood forest residue-type materials. Panel test results indicate strength properties of experimental boards produced from forest residue-type materials are suitable for use in engineered applica- tions. In this analysis of the manufac- turing costs of experimental three-layer flakeboard compositions and estimates of investment and operating costs, produc- tion costs were computed for 16 possible structural flakeboard sites in north and south regions of the United States. Large economics of scale were indicated by evaluating four sizes of facilities.

Production costs computed for manu- facturing structural flakeboard include taxes and profits, as well as other manu- facturing costs. By computing structural flakeboard production costs, excluding wood costs; then computing the coefficient for converting wood cost per ovendry ton to production costs that include addi- tional selling expense and tax and profit costs, total production costs were ex- pressed in equation form. A method was presented to calculate production costs, including wood cost, as a function of wood costs--the most variable element considered.

Assessments of feasibility was made by matching expected production costs against likely f.o.b. mill value of product output. Also, it was shown how commercial feasibility may be more directly assessed by matching likely wood supply costs to the maximum wood costs supportable by estimated f.o.b. mill market value for panel output.

In the analyses presented here the stature of preliminary assessments is assumed in which actual pre-investment analyses must consider proprietary and intangible aspects not considered. Additionally, it is suggested that, when possible, by remodeling a largely depreciated particleboard facility for production of structural flakeboard, investment and production costs may be greatly reduced.

References

1. Harpole, George B. 1978. Cash flow analysis computer program for analyzing manufacturing investment. USDA For. Serv. Res. Pap. FPL 305. For. Prod. Lab., Madison, Wis.

2. Ince, Peter J., and George B. Harpole. 1977. PARVCOST: A Particleboard Variable Cost Program. USDA For. Serv. Gen. Tech. Rep. FPL-14. For. Prod. Lab., Madison, Wis.

STRUCTURAL FLAKEBOARD MANUFACTURING PROCESS
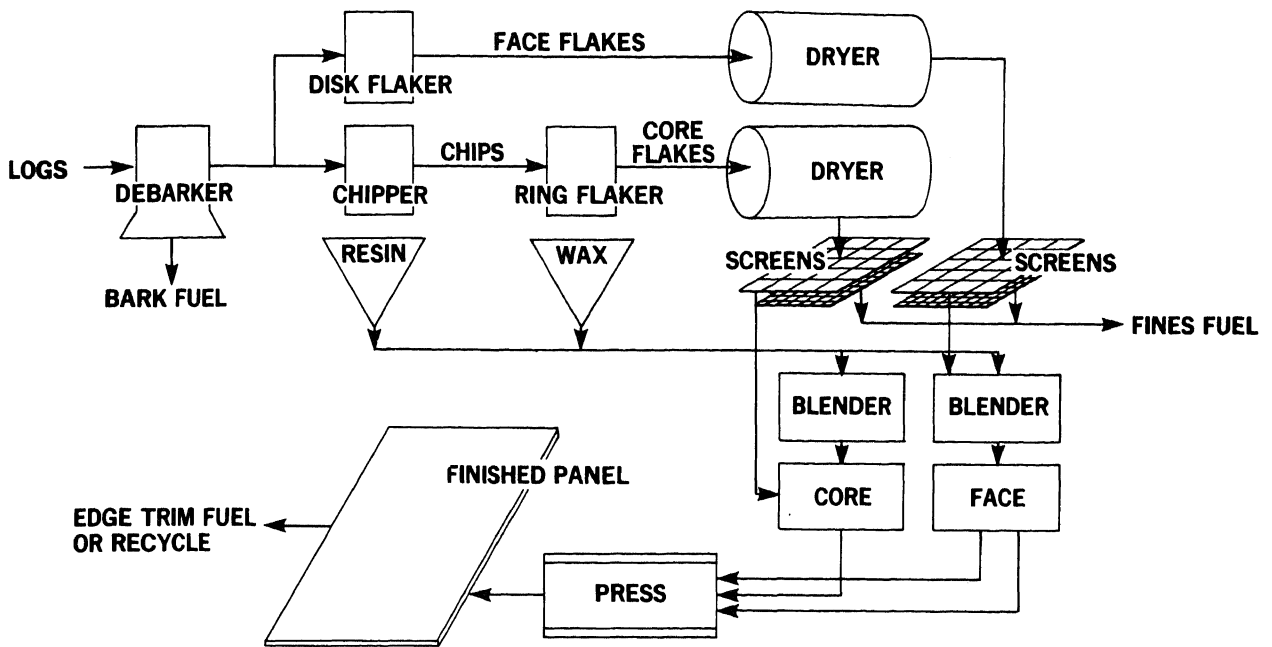
Figure 1.--Structural flakeboard manufacturing process.

Table 1.--AVERAGE INVESTMENT REQUIREMENTS FOR MANUFACTURING STRUCTURAL FLAKEBOARD, 1976 BASIS.

	Annual Output Capacity (MMSF, 1/2-in. basis)							
	37.5[1]		75 [2]		112.5[3]		150 [4]	
	N[5]	S[5]	N	S	N	S	N	S
	Thousand $							
100 PERCENT FLAKES								
Facilities	8,384	7,820						
Working capital	446	388						
Total	8,830	8,208						
40 PERCENT FLAKES / 60 PERCENT CHIPS								
Facilities	9,605	9,009	13,621	12,855	17,539	16,364	23,878	21,690
Working capital	468	422	758	654	1,058	907	1,373	1,177
Total	10,073	9,431	14,379	13,509	18,597	17,271	25,251	22,867
40 PERCENT LOGS / 60 PERCENT CHIPS								
Facilities	11,630	10,877	16,197	14,876	20,798	18,663	27,292	24,268
Working capital	747	648	1,203	1,024	1,666	1,402	2,143	1,797
Total	12,377	11,525	17,400	15,900	22,464	20,065	29,435	26,065

[1] Press size: 4- by 8-ft.

[2] Press size: 4- by 16-ft.

[3] Press size: 4- by 24-ft.

[4] Press size: 8- by 24-ft.

[5] N, north; S, south.

Table 2.--EXAMPLE OF DISCOUNTED CASH-FLOW ANALYSIS USED FOR ASSESSING PRODUCTION COSTS.

STRU. F.B.(SOUTH)**112.5MM-1/2" 4X24 240PG, 40PCT FLAKES, 60PCT CHIPS **ARCATA, CALIF. (X=WOOD)
(INVESTMENT TAX CREDIT OF $1417300. CONSIDERED.)

INITIAL INVESTMENT--YEAR 0		EFFECTIVE TAX RATE .5268	ORIGINAL CASH EQUITY $ 0.	VAR. COSTS/SALES = .4997
FACILITIES COST $1649500.		BORROWING RATE .0000	ENDING VALUE OF EQUITY $2077768.	FIXED COSTS/SALES= .2364
WORKING CAPITAL $ 715261.		REINVESTMENT RATE .0000	FACILITIES SALVAGE VALUE $ 0.	TAX COSTS/SALES = .1299
TOTAL INVEST. $17210261.		INTERNAL ROR .1500	P.V. OF INVST.(I=.1500) $ 2975300.	A.T. PROFIT/SALES= .1340

FINANCIAL SUMMARY WITH BREAK-EVEN ADJUSTED UNIT PRICES

YEAR-END VALUES . . .	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9	YEAR 10
UNIT SALES	50175.	94680.	112500.	112500.	112500.	112500.	112500.	112500.	112500.	112500.
UNIT PRICE $	116.22 $	122.03 $	128.13 $	134.54 $	141.27 $	148.33 $	155.75 $	163.53 $	171.71 $	180.29
GROSS SALES $	5831325. $	11553868.$	14414878.$	15135621.$	15892402.$	16687022.$	17521374.$	18397442.$	19317313.$	20283179.
INTEREST INC-EXP	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
GROSS REVENUES $	5831325.$	11553868.$	14414878.$	15135621.$	15892402.$	16687022.$	17521374.$	18397442.$	19317313.$	20283179.
RAW MATERIAL COST $	1995108.$	3952999.$	4931854.$	5178047.$	5437369.$	5709238.$	5994700.$	6294435.$	6609156.$	6939614.
PROCESSING LABOR	485571.	764736.	802973.	843121.	885277.	929541.	976050.	1024819.	1076060.	1129863.
SELLING EXPENSE	583132.	1155387.	1441488.	1513562.	1589240.	1668702.	1752137.	1839744.	1931731.	2028318.
TOTAL VAR COST $	3063812.$	5873121.$	7176315.$	7535130.$	7911887.$	8307481.$	8722855.$	9158998.$	9616948.$	10097795.
UNIT VAR COST $	61.06 $	62.03 $	63.79 $	66.98 $	70.33 $	73.84 $	77.54 $	81.41 $	85.48 $	89.76
PROFIT CONTRI $	2767513.$	5680747.$	7238563.$	7600491.$	7980515.$	8379541.$	8798518.$	9238444.$	9700365.$	10185384.
ADMIN. OVERHEAD $	428780.$	450219.$	472730.$	496366.$	521185.$	547244.$	574606.$	603336.$	633503.$	665178.
FACTORY OVERHEAD	1381250.	1450312.	1522828.	1598969.	1678918.	1762864.	1851007.	1943557.	2040735.	2142772.
TOTAL F.C. $	1810030.$	1900531.$	1995558.$	2095336.$	2200103.$	2310108.$	2425613.$	2546894.$	2674238.$	2807950.
FACILITIES COST $	0.$	0.$	0.$	0.$	0.$	0.$	0.$	0.$	0.$	-2975300.
WORKING CAPITAL	348004.	185390.	64433.	67654.	71037.	74589.	78318.	82234.	86346.	-1813267.
INVESTMENT $	348004.$	185390.$	64433.$	67654.$	71037.$	74589.$	78318.$	82234.$	86346.$	-4788568.
DEPRECIATION $	2654900.$	2144700.$	1736500.$	1410000.$	1148700.$	959000.$	959000.$	959000.$	959000.$	959000.
AFTER TAX PROFIT $	614082.$	773926.$	1659278.$	1937827.$	2191726.$	2418257.$	2561860.$	2712643.$	2870965.$	3037203.
A.T. EARNINGS	3268982.	2918626.	3395778.	3347827.	3340426.	3377257.	3520860.	3671643.	3829965.	3996203.
A.T. NET CASH FLOW	2880979.	2733236.	3331345.	3280173.	2899289.	3302668.	3442542.	3589408.	3743619.	8784771.
ACUM NET CASH FLOW $-14329.3M	$-11596.0M	$ -8264.7M	$ -4984.5M	$ -2085.2M	$ 1217.4M	$ 4660.0M	$ 8249.4M	$11993.0M	$ 20777.8M	

INTERNAL RATES OF RETURN * * * AT ADJUSTED INPUT VALUES					
	80 PCT	90 PCT	100 PCT	110 PCT	120 PCT
UNIT SALES	.099	.126	.150	.173	.195
UNIT PRICE	.062	.109	.150	.188	.223
UNIT VAR COST	.195	.172	.150	.127	.102
TOTAL F.C.	.157	.157	.150	.143	.136
FACILITIES COST	.182	.165	.150	.137	.126

146

FOREST REGIONS

PACIFIC
FOREST

ROCKY MT.
FOREST

HARDWOOD
FOREST

TROPICAL
FOREST

SOUTHERN
FOREST

TROPICAL
FOREST

NORTHERN
FOREST

Figure 2.--Sixteen sites in U.S. North and South used for economic assessments
of structural flakeboard manufacture.

SITES: NORTHERN INTEMPERATE CLIMATES (N), SOUTHERN TEMPERATE CLIMATES (S)

ANNUAL OUTPUT	37.5 MMSF 1/2"			75 MMSF 1/2"		112.5 MMSF 1/2"		150 MMSF 1/2"	
PRESS SIZE	4' X 8'			4' X 16'		4' X 24'		8' X 24'	
FURNISH SOURCES	100% FLAKES	FLAKES & CHIPS	LOGS & CHIPS	FLAKES & CHIPS	LOGS & CHIPS	FLAKES & CHIPS	LOGS & CHIPS	FLAKES & CHIPS	LOGS & CHIPS

PRODUCTION COSTS ($/MSF 1/2")
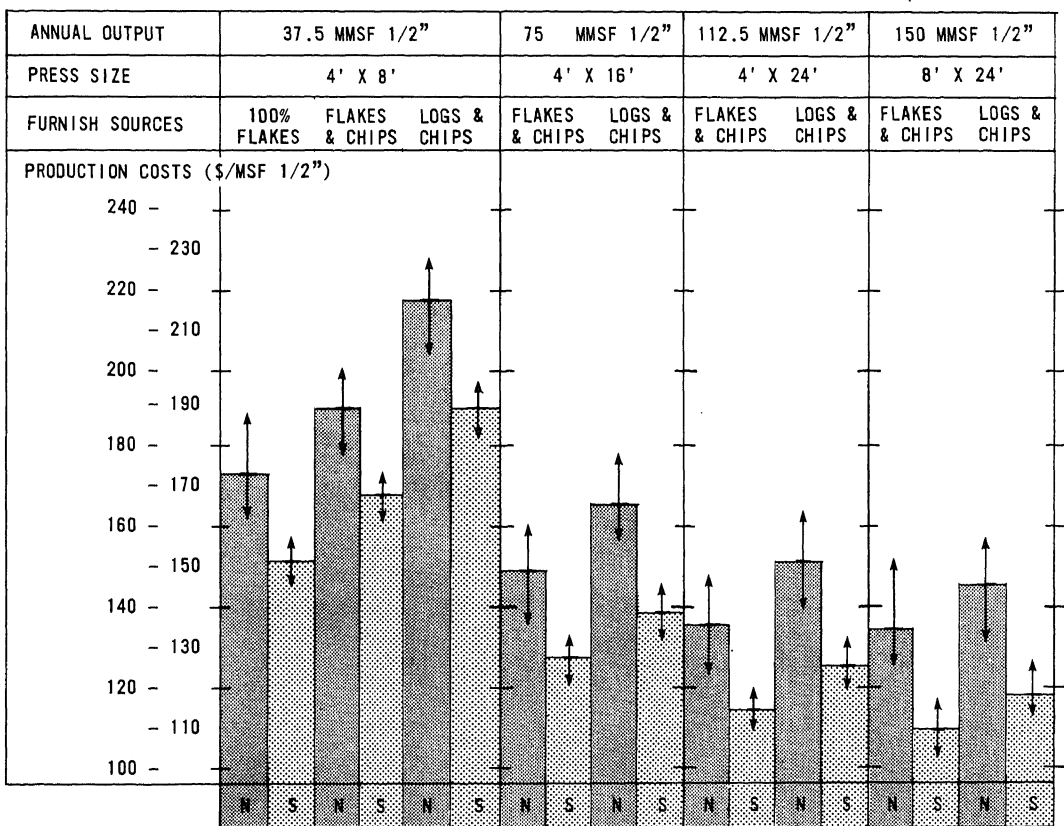
Figure 3.--Average (—), low (∨), and high (∧) production costs, excluding
wood costs, 1976 basis.
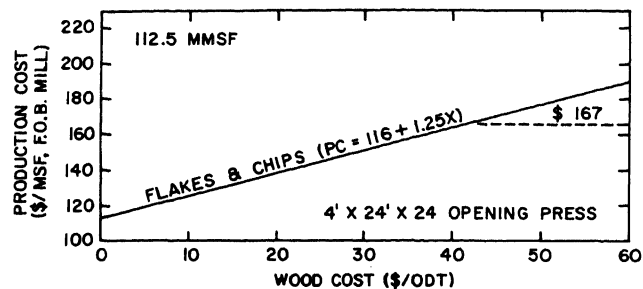
Figure 4.--Production cost (PC) vs wood cost
(WC = coeff · X), including taxes, profit (15% IRR), and
selling expense (5, 3, and 2%) for manufacture of 1/2-inch
structural flakeboard at Arcata, Calif., 1976 basis.

Table 3.-- RAW MATERIAL AND ENERGY REQUIREMENTS FOR MANUFACTURE
OF STRUCTURAL FLAKEBOARD AT AN ARCATA, CALIF., SITE

Raw Materials and Energy	Requirements per MSF, 1/2-inch Basis
Wood (OD spec. grav. = .41)[1]	
OD wood (lb)	2,129.8
Green wood (lb)	2,768.8
Solid wood (ft^3)	83.3
Resin (lb)	100.7
Wax (lb)	20.1
Heat-energy (million Btu)	3.532
Electric power (kWh)	162.1

[1]Wood requirements expressed in alternate standards of measure.

148

Table 4.--RAW MATERIAL AND ENERGY REQUIREMENT COSTS FOR MANUFACTURE
OF STRUCTURAL FLAKEBOARD AT AN ARCATA, CALIF., SITE, 1976 BASIS

Requirements	Cost
	$/MSF, 1/2-in. basis
Wood ($.42/ft^3)	35.16
Resin (5%, $.30/lb)	30.21
Wax (1%, $.19/lb)	3.83
Elec. power ($.02/kWh)	3.24
Dryer heat ($.62/million Btu)	.75
Process steam ($.62/million Btu)	1.74
Total unit cost	74.93

Table 5.--AVERAGE PRODUCTION COSTS FOR MANUFACTURING STRUCTURAL FLAKEBOARD
AT ARCATA, CALIF., 1976 BASIS.

Type of Cost	Production Costs		
	Without wood	With wood[1]	Difference
	----------------$/MSF, 1/2-inch--------------------		
Raw materials	39.77	74.93	35.16
Processing labor	6.67	6.67	---
Selling expense (10%)	11.62	15.73	4.11
Total variable costs	58.06	97.33	39.27
Overhead	17.07	17.07	---
Depreciation	10.41	10.41	---
Total manufacturing	85.54	124.81	39.27
Taxes (53%)	15.08	16.01	.93
Profit (15%)	15.58	16.50	.92
Total production	116.20	157.32	41.12

[1] Wood cost = $33/ODT.

PRODUCTION OPPORTUNITIES IN FOUR SOUTHERN LOCATIONS

Peter Koch[1,2,3]
Chief Wood Scientist
Southern Forest Experiment Station
USDA Forest Service
New Orleans, Louisiana

Abstract

Flakeboard manufactured from a species mix of 60-percent dense hardwoods and 40-percent soft hardwoods or southern pine can be manufactured profitably in southern plants whose annual capacities range from 37.5 to 150 MMSF, 1/2-inch basis. The 1/2-inch flakeboards will weigh about 50 pounds per cubic foot and can be delivered to retail yards in the Midwest, South, and East at prices $20 to $90 lower per MSF than the 1977 average sale price of 1/2-inch, 3-ply CDX southern pine plywood. Plants will operate most profitably on residual flakes from other manufacturing operations; wood supplied as flakes and chips will yield more profit than that supplied as chips and roundwood. Large plants will be more profitable than small plants. Of plant locations studied, south Georgia and the Arkansas-Missouri border have the highest profit potential; plants on the Texas-Louisiana border and in West Virginia appear slightly less promising. However, even the poorest location indicates after-tax profits in excess of 15 percent on entire capital requirement while underselling 1/2-inch southern pine plywood by $20/MSF (based on 1977 plywood prices). Total capital requirements range from $8.2 to $28.9 million, depending on plant capacity, type of wood processed, and plant location.

Introduction

By the year 2000 about half of all softwood harvested in the United States will be southern pine--largely committed to production of lumber, plywood, poles, fiberboard, particleboard, and pulp. Little surplus volume will be available to supply a major new commodity market such as that anticipated for structural exterior flakeboard.

There is, however, a major under-utilized wood resource in the South--hardwoods growing on southern pine sites. On these sites, about 0.8 cubic foot of hardwoods are present for every cubic foot of southern pine. Twenty-two species account for over 90 percent of the hardwood volume. Eleven of the 22 species are oaks, and they comprise nearly half of the volume. Sweetgum and hickory are the next leading species. About half the volume is in trees 5 to 11.9 inches in d.b.h. and averaging 40 to 70 years of age. The remainder is about equally divided between trees 12 to 14.9 inches d.b.h. and trees 15 inches or larger (8). With the exceptions of yellow-poplar, sweetbay, sweetgum, and red maple (the soft hardwoods) all exceed 0.5 specific gravity (Table 1).

Species mix varies with location, but throughout the South (except in northern Arkansas and southern Missouri) a mix of approximately 60-percent hard hardwoods and 40-percent softwoods and soft hardwoods is available. From such a mix, a structural flakeboard can be fabricated to a shipping weight of 47 to 50 pounds per cubic foot (2,9).

In northern Arkansas and southern Missouri less than 10 percent of the hardwood resource is soft hardwoods and southern pine is in limited supply. Oaks and hickories, however, are plentiful. Flakeboards containing mostly oak and hickory may have shipping weights of 50 to 54 pounds per cubic foot, slightly higher than that of boards made with a mix containing softwoods and soft hardwoods. In this analysis, flakeboards from all southern locations have been assigned a shipping weight of 2,083 pounds per 1,000 square feet of 1/2-inch board, or 50 pounds per cubic foot.

Species	Percent of Total Volume[2]	Stemwood Specific Gravity[3]	Stemwood Moisture Content[4]	Weight of Bark-Free Green Stemwood
			%	Pcf
Ash, green	0.9	0.561	47.4	51.6
white		.582	47.5	53.6
Elm, American	1.4	.536	75.5	58.7
winged		.623	65.6	64.4
Hackberry	.1	.525	72.6	56.5
Hickory, true	8.5	.643	51.5	60.8
Maple, red	3.6	.496	69.9	52.6
Oak, black	4.0	.620	69.2	65.5
blackjack	<.1	.638	74.2	69.4
cherrybark	1.2	.633	66.6	65.8
chestnut	4.2	--[5]	--[5]	--[5]
laurel	1.4	.582	74.4	63.3
northern red	2.4	.605	69.7	64.1
post	7.0	.659	65.6	68.1
scarlet	3.6	.622	69.4	65.7
Shumard	.2	.625	69.1	65.9
southern red	8.1	.609	70.1	64.6
water	4.7	.587	73.6	63.6
white	12.3	.665	61.9	67.2
Sweetbay	.6	.437	100.8	54.8
Sweetgum	13.2	.453	120.4	62.3
Tupelo, black	5.5	.500	90.0	59.3
Yellow-poplar	7.0	.395	111.7	52.2
Other hardwoods	10.1	--	--	--
Total	100.0			

[1]Data from Manwiller (7).

[2]Data from Christoper et al. (1).

[3]Basis of ovendry weight and volume when green.

[4]Dry weight basis.

[5]Data not available.

The foregoing summarizes hardwood survey data specific to southern pine sites. Additional state and regional data are periodically available, however, for the hardwood resource on all site classes. Readers interested in the most current survey data should direct their queries to the Southern and Southeastern Forest Experiment Stations of the U.S. Forest Service. A bibliography of recent references containing data on the 12-state southern region plus Missouri and West Virginia follows this report.

The hardwood species on pine sites are spread across the 12 southern states (Table 2). Large volumes also grow in Missouri and West Virginia. Their distribution in the 12 southern states is shown in maps provided by Christopher et al.(1).

Table 2. - VOLUMES OF HARDWOODS ON SOUTHERN PINE SITES BY STATE(1).[1]

Species	Ala-bama	Arkan-sas	Flor-ida	Geor-gia	Loui-siana	Missis-sippi	North Caro-lina	Okla-homa	South Caro-lina	Tennes-see	Texas	Vir-ginia
						Million ft^3						
Ash, sp.	53	50	2	45	42	29	42	5	42	42	33	56
Elm, sp.	68	102	4	80	47	82	63	18	71	26	64	43
Hackberry, sp.	8	5	1	2	3	4	6	1	9	4	13	1
Hickory, sp.	850	518	37	501	197	356	422	88	185	492	155	372
Maple, red	126	41	23	244	51	53	502	2	153	147	25	384
Oak, black	255	353	--	188	19	94	219	53	78	333	20	337
cherrybark	43	109	--	12	110	120	40	1	52	6	69	17
chestnut	285	--	--	224	--	3	300	--	35	571	--	685
laurel	95	--	146	254	42	12	--	--	113	--	18	3
northern red	105	221	--	148	--	6	150	12	55	208	--	264
post	381	801	15	252	307	453	261	226	132	139	405	72
scarlet	166	2	--	247	--	39	420	--	94	321	--	510
Shumard	25	15	1	12	3	46	--	4	6	2	6	--
southern red	602	589	49	418	446	568	357	35	170	132	343	285
water	379	112	104	459	254	217	293	6	268	1	219	20
white	633	893	8	573	283	438	1,022	62	287	530	180	1,149
Sweetbay	82	1	60	37	36	63	7	--	2	--	10	2
Sweetgum	950	611	93	1,055	690	531	804	32	636	53	554	499
Tupelo, black	323	216	158	575	154	233	298	18	296	111	124	204
Yellow-poplar	419	1	14	616	10	122	946	--	210	278	--	805
Other hardwoods	609	286	363	658	391	358	686	70	464	328	355	410
Total	6,456	4,926	1,078	6,600	3,085	3,827	6,838	633	3,358	3,724	2,593	6,118

[1]Volumes of bark-free wood in trees $\geq$ 5 in. d.b.h. outside bark, to a 4-in. top measured outside bark.

.These numerous publications verify
t hardwood resources are adequate for
keboard manufacturing operations at
y southern locations. Optimum sites
which to manufacture flakeboard are
solely determined by wood supply,
ever. Price and freight structure in
tern, southern, and midwestern ply-
d markets are also major factors.

Plywood Price and Freight Structure

Flakeboard sheathing will compete in
ce and function with CDX flakeboard
athing made from Douglas-fir and
thern pine. To enter the market,
-inch flakeboard probably must
ersell 3-ply southern pine, the most
nomical 1/2-inch plywood sheathing.
ause flakeboard sheathing is heavier
harder to nail than plywood sheathing
the same thickness, it seems likely
a price differential will be needed
induce carpenters to use the heavier
duct. It might be noted, however,
flakeboard weighs no more than
sum board which carpenters handle
tinely without undue difficulty.
e manufacturers contemplating flake-
rd production feel that floor underlay-
provides easiest market entry,
ause the heavy flakeboard panels are
e easily handled at floor level than
roofs.

Mill prices and delivered prices for
athing are dependent on the cost of
nsportation to market. For example,
ed on December 1977 freight rates,
Texas mills undersold West Coast
ls in all eastern markets studied;
eover, the east Texas plywood mills
eived (f.o.b. mill) about $11 more
MSF, 1/2-inch, 3-ply sheathing than
West Coast mills (Tables 3 and 4).

Plywood mills throughout the South
erally obtain f.o.b. mill prices that
le them to meet delivered prices by
Texas mills, i.e., all the southern
s deliver plywood to market destina-
s at about the same price (Table 4,
t-hand column).

Plant Location and Freight Costs

As previously noted, mill prices for
athing are dependent on the cost of
nsportation to market (Tables 3 and 4).

Because the wood resource for flake-
rd is distributed throughout the South,
locations can advantageously serve
e markets. Four such locations, with
ciated markets, are listed (Table 5A).

The towns named as possible mill
s are not necessarily optimum; they
red, however, as locations from which
ase transportation charges to markets.
transport costs to representative
ets range from about $10 to over $25/
1/2-inch flakeboard (Table 5B). Rail

freight from Crockett, Texas, to Kansas
City seems disproportionately high ($25.88);
lower transport costs could perhaps be
achieved from a different location in the
general area.

Approximate costs to truck 1/2-inch
flakeboard from these locations are:

Origin and destination	Minimum load	
	24,000 lb.	30,000 lb.
	$/MSF	
Crockett, Tex.		
Houston	--	21.45
Kansas City	61.03	--
Hoxie, Ark.		
St. Louis	30.00	--
Chicago	47.91	--
Waycross, Ga.		
Tampa	--	29.16
Mobile	--	36.66
Grafton, W. Va.		
Pittsburgh	28.33	27.29
New York	43.12	41.24

Estimated Sales Price Obtainable

To predict f.o.b. mill prices for
1/2-inch flakeboard sheathing, a delivered
price at which the retailer will switch
from plywood to flakeboard must first be
estimated. Because flakeboard from
southern hardwoods is heavier and harder
to nail than plywood, it will probably
have to be offered at a lower price
(perhaps $20/MSF) than plywood. On the
basis of 1977 prices for plywood, this
assumption results in f.o.b. mill prices
in the range from $192 to $218/MSF,
depending on mill and market locations
(Table 5B).

It is recognized that plywood prices
were at record high levels in 1977, but
it seems doubtful that they will be
appreciably lower in the years ahead. It
is worth noting, however, that during the
low market of 1974, f.o.b. mill prices for
1/2-inch plywood were nearly $100/MSF
lower than the 1977 average.

Table 3. - PRICE PAID BY RETAILERS AT EIGHT LOCATIONS FOR 1/2-INCH CDX
DOUGLAS-FIR 3-PLY SHEATHING PLYWOOD, BASED ON AVERAGE 1977 MILL PRICES
AND DECEMBER 1977 FREIGHT RATES

Retail Location	Rail Freight per CWT from Portland[1]	Freight/MSF[2]	F.O.B. West Coast Mill Price[3,4]	Price Paid by Retailer for Sheathing
		$		
Houston	2.63	40.11	211	251
Kansas City	2.39	36.45	211	247
St. Louis	2.63	40.11	211	251
Chicago	2.66	40.57	211	252
Tampa	3.20	48.80	211	260
Mobile	2.99	45.60	211	257
Pittsburgh	3.16	48.19	211	259
New York	3.20	48.80	211	260

[1] 85,000-lb. rate on first four destinations and 75,000-lb. minimum on last four destinations.

[2] Based on 1,525 lb/MSF.

[3] Average for 1977; from this price, the retailer got only a 2% cash discount for payment in 10 days.

[4] 4- and 5-ply sheathing sells f.o.b. mill at a price about $9 higher than these values for 3-ply.

Table 4. - PRICE PAID BY RETAILERS AT EIGHT LOCATIONS FOR 1/2-INCH CDX
SOUTHERN PINE 3-PLY SHEATHING PLYWOOD, BASED ON AVERAGE 1977 EAST TEXAS
MILL PRICES AND DECEMBER 1977 FREIGHT RATES

Retail Location	Rail Freight per CWT From East Texas[1]	Freight/MSF[2]	F.O.B. East Texas Mill Price[3]	Price Paid by Retailer for Sheathing
		$		
Houston	0.44	6.71	222	229
Kansas City	1.05	16.01	222	238
St. Louis	1.04	15.86	222	238
Chicago	1.30	19.83	222	242
Tampa	1.35	20.59	222	243
Mobile	.86	13.12	222	235
Pittsburgh	1.75	26.69	222	249
New York	2.13	32.48	222	254

[1] Based on average shipment weight of 115,000 lb. per car.

[2] Based on 1,525 lb/MSF.

[3] Average for 1977; from this price the retailer got only a 2% cash discount for payment in 10 days.

TABLE 5A. - MILL LOCATIONS AND THEIR ASSOCIATED MARKETS

Mill Location	Major Market	Extended Market
Texas-Louisiana border (e.g., Crockett, Tex.)	Dallas-Ft. Worth Houston Waco San Antonio Austin Abilene	St. Louis Kansas City Wichita Topeka Oklahoma City Tulsa
Arkansas-Missouri border (e.g., Hoxie, Ark.)	St. Louis Kansas City	Chicago Indianapolis Cincinnati Topeka
South Georgia (e.g., Waycross)	Savannah Atlanta Jacksonville Tampa Miami Gainsville Orlando Tallahassee	Mobile Birmingham Huntsville
Northern West Virginia (e.g., Grafton)	Columbus Cleveland Washington, D.C. Pittsburgh Wheeling	Boston New York Buffalo

Table 5B.- POTENTIAL MILL-MARKET LOCATION, FOB MILL SALES PRICES, FREIGHT COSTS, AND ESTIMATED DELIVERED SALES PRICES FOR 1/2-INCH STRUCTURAL EXTERIOR FLAKEBOARD SHEATHING

Mill Location	Major Market	Extended Market	Flakeboard Freight to[1]		Price Delivered to Retailer [2]		Estimated Flakeboard Sales Price F.O.B. Mill[3]	
			Major market	Extended market	Major market	Extended market	Major market	Extended market
			----------------------- $/MSF ------------------------					
Crockett, Texas	Houston	Kansas City	9.17	25.88	209	218	200	192
Hoxie, Arkansas	St. Louis	Chicago	11.71	20.78	218	222	206	201
Waycross, Georgia	Tampa	Mobile	10.14	15.62	223	215	213	199
Grafton, West Virginia	Pittsburgh	New York	10.55	18.33	229	234	218	216

[1] Based on 90,000-lb car containing 43207 MSF, 1/2-in. flakeboard with shipping weight of 50 pcf.

[2] Priced to undersell 1/2-in. 3-ply CDX southern pine plywood sheathing by $20/MSF, based on 1977 average plywood prices.

[3] From this price the retailer will get only a 2% discount for payment of invoice within 10 days.

Production Cost

Total mill price must include wood costs and production costs; production costs on p. 134 include the costs of raw material (except wood), manufacturing, selling, overhead, discounts, commissions, and a profit on the entire capital requirement sufficient to yield about 15 percent return after state and Federal taxes.

These production costs vary according to plant location, plant capacity and form of wood entering the plant (i.e., roundwood requiring debarking or residual bark-free chips or flakes residual from other manufacturing operations). The relationships among these variables are mathematically expressed in Table 6 and illustrated in Figures 1 and 2.

Capital Requirements

Capital requirements during the first 10 years of plant life will vary with location, type of wood, and plant capacity, but can be summarized as follows:

Annual plant capacity and raw material	Cost
MMSF, 1/2-inch basis	million $
37.5	
Flakes	8.2 - 8.7
Flakes and chips	9.4 - 9.9
Chips and roundwood	11.5 - 12.2
75	
Flakes and chips	13.4 - 14.2
Chips and roundwood	15.8 - 17.1
112.5	
Flakes and chips	17.2 - 18.3
Chips and roundwood	19.9 - 22.1
150	
Flakes and chips	22.7 - 24.9
Chips and roundwood	25.9 - 28.9

For all plants, capital costs were estimated to be least in the Georgia location, and most in West Virginia.

Conclusions and Discussion

Except for mills with smallest annual capacity using roundwood, all flakeboard plants could be profitable at all locations using any of the forms of wood supply. Large plants will be more profitable than small plants if wood costs are the same for both.

The amount by which estimated f.o.b. mill sales price exceeds (or falls short of) estimated mill cost, including 15-percent after tax profit on entire capital requirement, varies with location (Table 7).

These amounts are based on 1976 wood costs. For each dollar per ovendry ton that current wood costs exceed those in Table 6, amounts will be reduced by $1.24 to $1.36/MSF. For example, if 1978 wood costs are $4 per ovendry ton higher than values in Table 6, spreads will be reduced $5 to $5.50/MSF.

Assuming flakes can be purchased for the same price as chips, plants will operate most profitably on residual flakes. A mixture of flakes and chips will yield more profit than a mixture of chips and roundwood.

All locations should accommodate profitable mills, but the south Georgia and Arkansas-Missouri border locations appear to offer the greatest profit potential. Although West Virginia is adjacent to markets that should pay most for sheathing (because of high freight costs from competing regions), manufacturing costs are estimated to be somewhat higher than in other southern locations, and estimated profit is therefore lower.

Best board properties will be achieved through use of precisely manufactured flakes. With present knowledge, precisely manufactured flakes cannot be cut from ordinary pulp chips or even from maxi-chips; flakes derived from such chips must therefore be used in panel cores and not in faces.

As previously explained, a small-capacity plant (37.5 MMSF per annum) might be supplied completely by residual flakes from a pallet, cross-tie, post, and stud mill using a 9-foot shaping-lathe headrig operating three shifts (3,4,5,6).

Plants of all sizes could be supplied with such flakes for use in faces, supplemented with maxi-chips to be ring-flaked and used in cores. Alternatively, roundwood could be processed through disk or drum flakers to yield face flakes, and maxi-chips could be ring-flaked for cores.

Table 6. - TOTAL MILL COSTS, INCLUDING WOOD, DISCOUNTS AND COMMISSIONS, AND 15 PERCENT AFTER-TAX PROFIT, TO MANUFACTURE 1 MSF, 1/2-INCH STRUCTURAL EXTERIOR FLAKEBOARD FROM MIXED SOUTHERN SPECIES[1].

Mill Location and Raw Material	Intercept a	Slope b	Estimated [1] Wood Cost X	Total Mill Cost [2]	Estimated Achievable Sales Price F.O.B. Mill [3]
			$/ODT	------ $/MSF ----------	
37.5 MMSF ANNUAL CAPACITY, 1/2-INCH BASIS					
Texas-Louisiana border					
Flakes[4]	144.12	1.28	16	165	192
Flakes and chips[5]	158.16	1.28	16	179	to
Roundwood and chips[6]	177.94	1.35	16	200	200
Arkansas-Missouri border					
Flakes	144.26	1.28	18	167	200
Flakes and chips	158.31	1.28	18	181	to
Roundwood and chips	178.13	1.35	16	206	206
South Georgia					
Flakes	141.83	1.28	18	165	199
Flakes and chips	155.46	1.28	18	179	to
Roundwood and chips	175.24	1.36	20	202	213
West Virginia					
Flakes	166.14	1.28	18	189	216
Flakes and chips	183.36	1.28	18	206	to
Roundwood and chips	206.02	1.36	19	232	218
75 MMSF ANNUAL CAPACITY, 1/2-INCH BASIS					
Texas-Louisiana border					
Flakes and chips	121.61	1.27	16	142	192 to
Chips and roundwood	132.96	1.34	16	154	200
Arkansas-Missouri border					
Flakes and chips	121.72	1.27	18	145	200 to
Roundwood and chips	133.10	1.34	16	155	206
South Georgia					
Flakes and chips	119.68	1.27	18	143	199 to
Roundwood and chips	130.85	1.34	20	158	213
West Virginia					
Flakes and chips	145.89	1.27	18	169	216 to
Roundwood and chips	160.44	1.34	19	186	218
112.5 MMSF ANNUAL CAPACITY, 1/2-INCH BASIS					
Texas-Louisiana border					
Flakes and chips	109.11	1.26	16	129	192 to
Roundwood and chips	117.94	1.33	16	139	200
Arkansas-Missouri border					
Flakes and chips	109.21	1.26	18	132	200 to
Roundwood and chips	118.05	1.33	16	139	206
South Georgia					
Flakes and chips	107.27	1.27	18	130	199 to
Roundwood and chips	115.82	1.34	20	143	213
West Virginia					
Flakes and chips	133.26	1.27	18	156	216 to
Roundwood and chips	145.87	1.34	19	171	218

Table 6. - Continued

Mill Location and Raw Material	Intercept a	Slope b	Estimated[1] Wood Costs X	Total Mill Cost[2]	Estimated Achievable Sales Price F.O.B. Mill[3]
150 MMSF ANNUAL CAPACITY, 1/2-INCH BASIS					
Texas-Louisiana border					
Flakes and chips	106.52	1.24	16	126	192 to
Roundwood and chips	114.27	1.31	16	135	200
Arkansas-Missouri border					
Flakes and chips	106.61	1.24	18	129	201 to
Roundwood and chips	114.38	1.31	16	135	206
South Georgia					
Flakes and chips	104.69	1.24	18	127	199 to
Roundwood and chips	112.11	1.31	20	138	213
West Virginia					
Flakes and chips	132.41	1.24	18	155	216 to
Roundwood and chips	142.97	1.31	19	168	218

[1] Based on 1976 regional wood prices and assuming that flakes residual from other manufacturing operations are priced the same as residual bark-free pulp chips; assumes 60% dense hardwoods and 40% soft hardwoods or softwoods. Costs are expressed in terms of wood cost per ovendry ton (X) in regression equations of the form: Production cost = a + bx.

[2] Includes selling allowance of 2% f.o.b. mill selling price plus $.50/MSF of rated annual output per year.

[3] From Table 5B.

[4] 100% flakes.

[5] 40% flakes and 60% chips.

[6] 40% chips and 60% barky roundwood.

Table 7. - AMOUNT BY WHICH ESTIMATED F.O.B. MILL SALES PRICE[1] EXCEEDS (OR FALLS SHORT OF) ESTIMATED MILL COST[2] INCLUDING 15% AFTER TAX PROFIT ON ENTIRE CAPITAL REQUIREMENT, FOR VARIOUS MILL LOCATIONS AND CAPACITIES.

Mill Location and Annual Capacity	Raw Material Entering Mill		
	Flakes	Flakes and chips	Logs and chips
MMSF	--------$/MSF, 1/2-inch basis----------		
Texas-Louisiana border			
37.5	31	17	(4)[3]
75.0	--	54	42
112.5	--	67	57
150.0	--	70	61
Arkansas-Missouri border			
37.5	36	22	(3)
75.0	--	58	48
112.5	--	71	64
150.0	--	74	68
South Georgia			
37.5	41	27	(4)
75.0	--	63	48
112.5	--	76	63
150.0	--	79	68
West Virginia			
37.5	28	11	(15)
75.0	--	48	31
112.5	--	61	46
150.0	--	62	49

[1] Average of values in last column in Table 6.

[2] From column "Total Mill Cost" in Table 6.

[3] Values in parentheses represent costs that exceed sales price.

References

1. Christopher, J. F., H.S. Sternitzke, R.C. Beltz, J. M. Earles, and M.S. Hedlund. 1976. Hardwood distribution on pine sites in the South. USDA For. Serv. Resour. Bull. SO-59. South. For. Exp. Sta., New Orleans, La.

2. Hse, C.-Y., P. Koch, C. W. McMillin, and E. W. Price. 1975. Laboratory-scale development of a structural exterior flakeboard from hardwoods growing on southern pine sites, pp. 143-144. In Proc. 9th WSU Particleboard Symp., Washington State Univ., Pullman, Wash.

3. Howe, J. P. and P. Koch. 1976. Dowel-laminated crossties--performance in service, technology of fabrication, and future promise. For. Prod. J. 26(5): 23-30.

4. Koch, P. 1975. Shaping-lathe headrig now commercially available. South. Lumberman 231(2872): 93-97.

5. Koch, P. 1976. Making dowel-laminated crossties with the shaping-lathe headrig--it should be profitable. South. Lumberman 233(2896): 82-83.

6. Koch, P. and R. A. Caughey. 1978. Shaping-lathe headrig can profitably yield solid-wood and molded-flake products from mixed hardwoods. For. Prod. J. (In press)

7. Manwiller, F. G. 1978. Wood and bark specific gravity of small-diameter, pine-site hardwoods in the South. Wood Sci. (In press)

8. Murphy, P. A. and H. A. Knight. 1974. Hardwood resources on southern pine sites. For. Prod. J. 24(7): 13-16.

9. Price, E. W. 1977. Basic properties of full-size structural flakeboards fabricated with flakes of a shaping lathe. In Proc. 11th WSU Particleboard Symp., Washington State Univ., Pullman, Wash.

Figure 1.--Production cost (PC) vs wood cost (coeff · X), including taxes, profit (15% IRR), and selling expense (5, 3, and 2%), for manufacture of 1/2-inch structural flakeboard at two locations. Single data points indicate a 1976 wood cost estimate, 60% dense hardwood/40% soft hardwood or softwood. Dashed line indicates probable f.o.b. mill price obtainable in primary and extended markets, based on average 1977 plywood prices (Tables 4, 5, and 6) and December 1977 rate freight rates.

Figure 2.--Production cost (PC) vs wood cost (coeff · X), including taxes, profit (15% IRR), and selling expense (5, 3, and 2%), for manufacture of 1/2-inch structural flakeboard at two locations. Single data points indicate a 1976 wood cost estimate, 60% dense hardwood/40% soft hardwood or softwood. Dashed line indicates probable f.o.b. mill price obtainable in primary and extended markets, based on average 1977 plywood prices (Tables 4, 5, and 6) and December 1977 rate freight rates.

<p style="text-align:center">Bibliography</p>

By state	Title
Alabama	
Beltz (1975a)	Alabama's timber resources updated, 1975
Hedlund and Earles (1973)	Forest statistics for Alabama counties
Murphy (1973)	Alabama forests: trends and prospects
Arkansas	
Beltz (1975b)	Arkansas's timber resources updated, 1975
Hedlund and Earles (1970)	Forest statistics for Arkansas counties
Van Sickle (1970)	Arkansas forest resource patterns
Georgia	
Morris and Steinbeck (1974)	Georgia's timber resources
Florida	
Knight and McClure (1971)	Florida's timber, 1970
Louisiana	
Bertelson (1974)	Louisiana forest industries, 1973
Earles (1975)	Forest statistics for Louisiana parishes
Maddocks (1976)	Hardwoods & wildlife--here today, here tomorrow. Part I: manage the hardwoods.
Murphy (1975)	Louisiana forests: status & outlook
Mississippi	
Beltz and Christopher (1970)	Computer program for updating timber resource statistics by county, with tables for Mississippi
Hedlund and Earles (1969)	Forest statistics for Mississippi counties
Van Sickle and Van Hooser (1969)	Forest resources of Mississippi
Missouri	
Essex and Spencer (1974)	Timber resources of Missouri's eastern Ozarks--'72
Hahn and Vasilevsky (1975)	Timber resources of Missouri's Prairie region
Ostrom (1974)	Timber volume in Missouri counties
North Carolina	
Cost (1975)	Forest statistics for the Mountain Region of North Carolina, 1974
Knight (1975a)	A preview of "North Carolina's timber, 1974"
Knight (1975b)	North Carolina's timberland acreage is declining
Knight and McClure (1966)	North Carolina's timber
South Carolina	
Knight and McClure (1969)	South Carolina's timber, 1968
Oklahoma	
Murphy (1977)	East Oklahoma forests: trends and outlook
Earles (1976a)	Forest statistics for east Oklahoma counties
Tennessee	
Hedlund and Earles (1971)	Forest statistics for Tennessee
Murphy (1972)	Forest resources of Tennessee
Texas	
Bertelson (1975a)	East Texas forest industries, 1974
Earles (1976b)	Forest statistics for east Texas piney woods counties
Murphy (1976)	East Texas forests: status and trends

rginia
Knight and McClure (1967)   Virginia's timber, 1966

st Virginia
Ferguson (1964)   The timber resources of West Virginia

ntire South

llamy (1972)   Southern pulpwood production, 1971
llamy (1974)   Southerm pulpwood production, 1973
ltz (1972)   Midsouth pulpwood movement
ltz and Bertelson   Timber resource statistics for Midsouth
  counties, 1971
rtelson (1973)   Southern pulpwood production, 1972
rtelson (1975b)   Southern pulpwood production, 1974
uikshank and McCormack (1956)   The distribution and volume of hickory
  timber
rles (1973)   Forest area statistics for Midsouth
  counties
ir (1966)   Projected demands for hardwood veneer
  emphasize research-management needs
rold (1976)   TVA is looking ahead at veneer timber
  opportunities
dlund and Knight (1969)   Hardwood distribution maps for the South
rtzler (1951)   Southern hardwoods for veneer and plywood
rphy[1]   The timber resource of the Midsouth
termeier (1975)   The South's forest products industries:
  a major industrial sector
igley (1971)   The supply and demand situation for oak
  timber
egel (1963)   The changing hardwood lumber industry
ernitzke (1973)   The South's timber resources: status
  and trends
ernitzke (1974)   Eastern hardwood resources: trends and
  prospects
ernitzke (1975)   Shifting hardwood trends in the South
ernitzke (1976)   Impact of changing land use on delta
  hardwood forests

[1]Murphy, P.A. The timber resource of the Midsouth. Paper presented at the
outh Section meeting of the For. Prod. Res. Soc., Jackson, Miss., Oct. 13-14, 1976.

phabetically as reference

Bellamy, T.R. 1972. Southern pulp-
d production, 1971. USDA For. Serv.
. Bull. SE-23,   Southeast.
. Exp. Stn., Asheville, N.C.

Bellamy, T.R. 1974. Southern pulp-
d production, 1973. USDA For. Serv.
our. Bull. SE-29,   Southeast
. Exp. Stn., Asheville, N.C.

Beltz, R.C. 1972. Midsouth pulpwood
ement. Pulpwood Prod. 20(4): 14,16.

eltz, R.C. 1975a. Alabama's timber
ources updated, 1975. USDA For. Serv.
. Bull. SO-55,   South. For.
. Stn., New Orleans, La

eltz, R.C. 1975b. Arkansas' timber
ources updated, 1975. USDA For. Serv.
our. Bull. SO-56, 10 p. South. For.
. Stn., New Orleans, La..

eltz, R.C. and D.F. Bertelson. 1971.
er resource statistics for Midsouth
ties, 1971. USDA For. Serv. Res.

Bull. SO-31,   South. For. Exp. Stn.,
New Orleans, La.

Beltz, R.C. and J.F. Christopher. 1970.
Computer program for updating timber
resource statistics by county, with
tables for Mississippi. USDA For. Serv.
Res. Bull. SO-23,   South. For. Exp.
Stn., New Orleans, La.

Bertelson, D.F. 1973. Southern pulp-
wood production, 1972. USDA For. Serv.
Res. Bull. SO-41,   South. For. Exp.
Stn., New Orleans, La.

Bertelson, D.F. 1974. Louisiana
forest industries, 1973. USDA For. Serv.
Res. Bull. SO-51,   South. For. Exp.
Stn., New Orleans, La.

Bertelson, D.F. 1975a. East Texas
forest industries, 1974. USDA For. Serv.
Res. Bull. SO-57,   South. For. Exp.
Stn., New Orleans, La.

Bertelson, D.F. 1975b. Southern
pulpwood production, 1974. USDA For.
Serv. Res. Bull. SO-54,   South.
For. Exp. Stn., New Orleans, La.

Cost, N.D. 1975. Forest statistics for the Mountain Region of North Carolina, 1974. USDA For. Serv. Resour. Bull. SE-31, Southeast. For. Exp. Stn., Asheville, N.C.

Cruikshank, J.W. and J.F. McCormack. 1956. The distribution and volume of hickory timber. USDA For. Serv. Hickory Task Force Rep. No. 5. Southeast. For. Exp. Stn., Asheville, N.C.

Earles, J.M. 1973. Forest area statistics for MidSouth counties. USDA For. Ser. Resour. Bull. SO-40. South. For. Exp. Stn., New Orleans, La.

Earles, J.M. 1975. Forest statistics for Louisiana parishes. USDA For. Serv. Resour. Bull. SO-52. South. For. Exp. Stn., New Orleans, La.

Earles, J.M. 1976a. Forest statistics for east Oklahoma counties. USDA For. Serv. Resour. Bull. SO-62. South. For. Exp. Stn., New Orleans, La.

Earles, J.M. 1976b. Forest statistics for east Texas pineywoods counties. USDA For. Serv. Resour. Bull. SO-60. South. For. Exp. Stn., New Orleans, La.

Essex, B.L. and J.S. Spencer, Jr. 1974. Timber resource of Missouri's eastern Ozarks--'72. USDA For. Serv. Resour. Bull. NC-19. North Cent. For. Exp. Stn., St. Paul, Minn.

Ferguson, R.H. 1964. The timber resources of West Virginia. USDA For. Serv. Resour. Bull. NE-2. Northeast. For. Exp. Stn., Upper Darby, Pa.

Hahn, J.T. and A. Vasilevsky. 1975. Timber resource of Missouri's Prairie Region. USDA For. Serv. Resour. Bull. NC-26. North Cent. For. Exp. Stn., St. Paul, Minn.

Hair, D. 1966. Projected demands for hardwood veneer emphasize research-management needs. For. Prod. J. 16(1): 28-30.

Harold, M.R. 1976. TVA is looking ahead at veneer timber opportunities. South. Lumberman 233(2895): 74-77.

Hedlund, A. and J.M. Earles. 1969. Forest statistics for Mississippi counties. USDA For. Serv. Resour. Bull. SO-15. South. For. Exp. Stn., New Orleans, La.

Hedlund, A. and J.M. Earles. 1971. Forest statistics for Tennessee counties. USDA For. Serv. Resour. Bull. SO-32. South. For. Exp. Stn., New Orleans, La.

Hedlund, A. and J.M. Earles. 1973. Forest statistics for Alabama counties. USDA For. Serv. Resour. Bull. SO-39. South. For. Exp. Stn., New Orleans, La.

Hedlund, A. and H.A. Knight. 1969. Hardwood distribution maps for the South. USDA For. Serv. Resour. Bull. SO-19. South. For. Exp. Stn., New Orleans, La.

28. Hertzler, R.A. 1951. Southern hardwoods for veneer and plywood. South. Lumberman 182(2279): 44-50.

Knight, H.A. 1975a. A preview of "North Carolina's timber, 1974." USDA For. Serv. Res. Note SE-224. Southeast. For. Exp. Stn., Asheville, N.C.

32. Knight, H.A. 1975b. North Carolina's timberland acreage is declining. USDA For. Serv. Res. Note SE-231. Southeast. For. Exp. Stn., Asheville, N.C.

Knight, H.A. and J.P. McClure. 1966. North Carolina's timber. USDA For. Serv. Resour. Bull. SE-5. Southeast. For. Exp. Stn., Asheville, N.C.

Knight, H.A. and J.P. McClure. 1967. Virginia's timber, 1966. USDA For. Serv. Resour. Bull. SE-8. Southeast. For. Exp. Stn., Asheville, N.C.

Knight, H.A. and J.P. McClure. 1969. South Carolina's timber, 1968. USDA For. Serv. Resour. Bull. SE-13. Southeast. For. Exp. Stn., Asheville, N.C.

Knight, H.A. and J.P. McClure. 1971. Florida's timber, 1970. USDA For. Serv. Resour. Bull. SE-20. Southeast. For. Exp. Stn., Asheville, N.C.

Maddocks, J. 1976. Hardwoods & wildlife--here today, here tomorrow. Part I: manage the hardwoods. Part II: pine trees for wildlife. For. & People 26(2): 10-13, 32-36; 14-16, 44-45.

Morris, D.J. and K. Steinbeck. 1974. Georgia's timber resource. Ga. For. Res. Pap. No. 77, 9 p.

Murphy, P.A. 1972. Forest resources of Tennessee. USDA For. Serv. Resour. Bull. SO-35. South. For. Exp. Stn., New Orleans, La.

Murphy, P.A. 1973. Alabama forests: trends and prospects. USDA For. Serv. Resour. Bull. SO-42. South. For. Exp. Stn., New Orleans, La.

Murphy, P.A. 1975. Louisiana forests: status & outlook. USDA For. Serv. Resour. Bull. SO-53. South. For. Exp. Stn., New Orleans, La.

Murphy. P.A. 1976. East Texas forests: status and trends. USDA For. Serv. Resour. Bull. SO-61. South. For. Exp. Stn., New Orleans, La.

Murphy, P.A. 1977. East Oklahoma forests. USDA For. Serv. Resour. Bull. SO-63.   South. For. Exp. Stn., New Orleans, La.

Ostermeier, D. 1975. The South's forest products industries: a major industrial sector. South. Lumberman 231(2872): 83-84.

Ostrom, A.J. 1974. Timber volume in Missouri counties. USDA For. Serv. Res. Note NC-179.   North Cent. For. Exp. Stn., St. Paul, Minn.

Quigley, K.L. 1971. The supply and demand situation for oak timber. pp. 30-36. In Proc. Oak Symp. USDA For. Serv. Northeast. For. Exp. Stn., Broomall, Pa.

Siegel, W.C. 1963. The changing southern hardwood lumber industry. South. Lumberman 206(2585): 83-86.

Sternitzke, H.S. 1973. The South's timber resources: status and trends. In The South's third forest--opportunities, action, responsibilities, pp. 5-11. La. State Univ. 22nd Ann. For. Symp. Proc.

Sternitzke, H.S. 1974. Eastern hardwood resources: trends and prospects. For. Prod. J. 24(3): 13-16.

Sternitzke, H.S. 1975. Shifting hardwood trends in the South. South. Lumberman 231(2872): 72-73, 42A.

Sternitzke, H.S. 1976. Impact of changing land use on delta hardwood forests. J. of For. 74: 25-27.

Van Sickle, C.C. and D.D. Van Hooser. 1969. Forest resources of Mississippi. USDA For. Serv. Resour. Bull. SO-17.   South. For. Exp. Stn., New Orleans, La.

Van Sickle, C.C. 1970. Arkansas forest resource patterns. USDA For. Serv. Resour. Bull. SO-24.   South. For. Exp. Stn., New Orleans, La.

Eugene M. Carpenter[1]
Market Analyst
North Central Forest Experiment Station
USDA Forest Service
St. Paul, Minnesota

Abstract

Virginia, Minnesota, was chosen as a potential flakeboard plant site because of an abundant underutilized aspen resource in the area. Volumes of forest and plant residues from harvesting and processing are not large. Nearly 80 percent of timber products output is pulpwood, and much of the sawlog output comes from small saw-timber trees. Two thirds of the 7.5 million acres of commercial forest land in a six county area surrounding Virginia is in public ownership and these lands are the main source of supply. Pulp chips are delivered to area mills for $21.00 to $25.50 per oven dry ton, roundwood rough pulpwood for approximately $18 per oven dry ton. The closest major market area is Minneapolis-St. Paul.

Introduction

When given the task of assessing the feasibility of a structural flakeboard plant in the North Central region, we chose the location of Virginia, Minnesota primarily because of the underutilized aspen forest resource in the area.

Virginia is located approximately 200 miles north of Minneapolis-St. Paul and 60 miles northwest of Duluth, where our research work unit is located. It is in the east central part of what is known as the 18 northern forested counties of Minnesota, an area that contains 82 percent of the commercial forest land in the state. Our resource assessment covers a 6-county area within an approximate 75-mile radius of Virginia (Fig. 1).

Current major wood use centers are located in International Falls on the Canadian border, Bemidji, Grand Rapids, Cloquet, and Duluth.

The area's economy is based largely on three industries: Taconite, tourism, and timber. Virginia is in the heart of the famous Mesabi Iron Range, and close to the famous Boundary Waters Canoe Area and the recently created Voyageurs National Park. Timbering peaked in Minnesota in 1899, and in the Duluth area in 1903. The Virginia area probably experienced the waning moments of big time lumbering in the Lake States following World War I. It was during this period that extensive timber cutting and subsequent slash fires gave rise to the large acreages of aspen now reaching maturity.

The area has long been characterized as having an underutilized forest resource. And, while we do not wish to overlook the opportunities of using forest residues in flakeboard production, we intend to highlight the opportunities of the standing timber resource. In the first place, it is illogical to consider rough, rotten and salvable dead trees as a material source while overlooking unused sound material. Secondly, I think we often consider that large volumes of forest residues are generated as a by-product of sawlog production. But in our study area, log production--and this is mostly sawlogs as we have extremely limited veneer production--is not large, accounting for slightly over 15-1/2 million cubic feet of harvest in 1973. This is contrasted to a cut of approximately 72 million cubic feet of pulpwood.

In addition, much of this sawlog volume, especially the hardwood--and the cut is about evenly divided between softwood and hardwood--comes from what would be recognized as small sawlog trees. Thus, slash is mostly relatively small tops and limbs. Nor do we have large volumes of unused primary plant residues. Most of the larger sawmills have chippers and produce pulp chips from coarse mill residues. The larger mills in the area produce 10 to 25 million board feet annually.

What we do have is an available resource of standing timber, primarily aspen, that is underutilized and needs harvesting.

Availability of the Forest Resource

I will be using data from the 1962 forest survey of Minnesota (4,5). A new survey has recently been completed, but very limited information is as yet available. In 1962, we had 8-1/2 million acres of unreserved commercial forest land in our 6-county study area. This has been reduced to slightly less than 7-1/2 million acres in 1975, primarily because of the expansion of the no-cut zone of the BWCA and the land placed in the Voyageurs National Park and restricted from harvest.

Of this area, 66 percent is in public ownership, 25 percent in private ownership, and six and one-half percent is owned by the forest industries (Table 1).

---

[1] Stationed at Duluth, Minn.

Table 1. - OWNERSHIP OF COMMERCIAL FOREST LAND, 1961-62

	Total	Federal	State	County	Industry	Private
	Thousand Acres					
	850.6	8.5	295.5	272.5	3.0	271.1
...n	367.0	8.5	51.6	103.5	10.9	192.5
	1,411.9	273.7	260.1	403.5	55.3	419.0
...hing	1,575.0	92.2	792.2	292.6	204.0	194.0
	1,104.0	513.6	157.0	154.0	126.0	153.4
...is	3,204.3	627.6	430.8	953.3	160.1	1,032.5
...l	8,512.8	1,524.1	1,987.2	2,179.4	559.3	2,262.8
		17.9%	23.3%	25.6%	6.6%	26.6%

...vey data showed approximately ...million cords of growing stock ...in the study area, in 1962 (Table 2). ...4-1/2 percent of this was softwood, ...percent aspen, and 24 percent other ...d; 74 percent was poletimber and ...nt sawtimber. At that time, a ...tion called managed harvest esti- ...hat it would be desirable to harvest ...ne million cords each of softwood ...en and a little less than 400,000 ...f other hardwoods.[2] Actual harvest ...t 500,000 cords of softwoods, ...cords of aspen, and 50,000 cords of ...ardwoods (Table 3). In 1973, the ...d cut was about 450,000 cords; aspen ...reased by about 92 percent to ...cords and other hardwoods doubled ...000 cords. Current growing stock ...nd an estimate of managed harvest ...available for the study area in the ...ture, from the North Central Forest ...nt Station.

...liminary data for a portion of the ...dicate current growing stock volumes ...early equal to the amount determined ...e 1962 survey in spite of the loss ...rcial forest acreage. The increased ...the vast amount of poletimber-sized ... in the years since the 1962 survey ...count for much of this. The flake- ...lls considered in this analysis ...approximately one cord of wood per ...inished board. Thus, the resource ...pport two of the larger-sized mills ...en. Should mixtures of aspen,

...aged Harvest is an area control ...e, and applies silvicultural guides ...rotation age, site index, and a ...nt objective to survey plot data to ... an amount that could be cut annu- ... the next 10 years, while improving ...cking and bringing about a more even ...tion of age classes.

birch, balsam fir, or tamarack be a de-sirable furnish, even larger production could be accommodated. Experimental boards from some of these species have been pro-duced and tested by the North Central Forest Experiment Station in cooperation with the University of Minnesota (2).

Cost of Manufacturing Structural Flakeboard

Production costs for the Virginia, Minnesota, mill site are estimated to range from $121.60 to $201.80/MSF 1/2 inch, excluding wood costs. These costs were computed using the PARVCOST and CFA programs developed by George Harpole at the Forest Products Laboratory in Madison, Wisconsin, and vary by the size of the facility and the expected furnish. Our furnish would likely be aspen roundwood or mixtures of aspen, birch, balsam fir, or tamarack. We will concentrate the analysis on the 60 per-cent chips, 40 percent roundwood furnish, and the 150- and 112.5-MMSF production facilities. These options include some front-end costs for debarking and flaking. In our calculations, we used a specific gravity of 0.38 for the furnish; this approximates a mixture of aspen with a small amount of birch. These species often grow in mixed stands, and this combination would offer an ideal utilization opportunity from silvicultural and timber harvesting stand-points. This specific gravity results in a board weight of about 1,873 pounds per MSF, 1/2-inch basis. Individuals could substitute their own values for the physical and economic variables as explained in George Harpole's presentation, "Overview of Structural Flakeboard Production Costs," and use the programs available from the Forest Products Laboratory to simulate structural flakeboard manufacture.

167

Production costs are $134.30/MSF, 1/2-inch for the 150-MMSF mill and $138.30/MSF for the 112.5-MMSF mill exclusive of wood costs. Estimated cost for rough aspen roundwood delivered to the mill is approximately $22 per cord or $20 per ovendry ton of wood (Table 4). While the cost for birch is slightly higher, the small amount used and the relatively small impact of wood cost on total cost would not affect the outcome appreciably. This then yields a total production cost of $157.02 and $161.48/MSF for the two larger mill capacities at Virginia.

Production costs for other facility options can be calculated from the equation: Total Cost = a + bX, where X is the expected wood cost per ovendry ton (Fig. 2). For example, comparable production costs per MSF would be $123 exclusive of wood and $150.35 including wood for a 112.5-MMSF mill using a combination of primary plant residues from a shaping lathe headrig and "maxi-chips" or fingerlings at $25 per ovendry ton delivered to the mill (1,3).

Likely Market Value for Structural Flakeboard

Structural sheathing is the primary market opportunity considered for structural flakeboard. CDX 4- or 5-ply, western softwood plywood dominates the Midwest market for this commodity. Other competitors are 3-ply CDX southern plywood and various sandwich panels. Although Minneapolis-St. Paul is the closest major market, Chicago and other Midwest markets would be needed to satisfy production requirements for an efficient-size mill. I will use Chicago as a base market in the following analysis, and because of shipping cost differentials, there would be a $3 to $8/MSF advantage in the Minneapolis-St. Paul area. This range is a result of cost differentials between contract common carrier and fleet trucking arrangements. Rail cost from Virginia to Chicago is $17/MSF, and is lower than contract common carrier truck rates, although more economical fleet arrangements could alter the differential.

Builder-distributor and wholesale accounts in the Chicago area paid from $200 to $249/MSF for CDX, 1/2 inch, 4- and 5-ply softwood plywood during 1976. The average price paid during 1976 was about $217/MSF. Mill-direct sales typically reflected only a 2 percent cash discount on invoices, after deducting freight, with the 5 and 3 percent functional middleman discounts rarely apparent in the distribution channels to the Chicago market. Allowing a 10 percent discount on the Chicago market for CDX 4- and 5-ply as the likely requirement to provide a price incentive for the introduction of structural flakeboard, the average market value of structural flakeboard might have been about $195/MSF. The average f.o.b. Virginia, Minn., value for 1/2-inch-thick structural flakeboard during 1976 would then have been about $178/MSF ($195, $17 freight cost).

Given our estimated unit production costs of $157 and $161.50 for the 150-MMSF and 112.5-MMSF mills, both facilities would appear to offer reasonable investment opportunities (Fig. 2). These production costs include wood, the fixed and variable costs, and profit as discussed by Harpole. The selling costs include provisions for the 2 percent discount, as well as an annual cost for the first 3 years of $.50/MSF of rated annual output to cover extraordinary promotional costs necessary when introducing a new product.

Discussion

It appears that the aspen resource in Northern Minnesota could support considerable structural flakeboard capacity from the standing growing stock inventory. A clearer picture will be available very soon from the recently completed state-wide forest survey. A small increase in delivered cost per cord might result from the increased road building needs and harvesting lower density stands. This would be moderated to the extent that better utilization or use of residues might increase supply.

Plant sites in the study area on the Burlington Northern railroad allow one-line hauls to a large Midwest area. A more competitive situation might result if increased shipping volume would allow reduced commodity rail rates. Currently, truck rates are lower to the Minneapolis market area.

References

1. Erickson, John R. 1976. Experimental trials with a spiral-head chipper to make hardwood fingerling chips for ring flakers. For. Prod. J. 26(6)50-53.

2. Gertjejansen, R.M., M. Hyvarinen, J. Haygreen, and D. French. 1973. Physical properties of phenolic bonded wafer-type particleboard from mixtures of aspen, paper birch, and tamarack. For. Prod. J. 23(6) 24-28.

3. Koch, P., and R.A. Coughey. 1978. Shaping-lathe headrig can profitably yield solid-wood and molded-flake products from mixed hardwoods. For. Prod. J. (In press).

4. Stone, Robert N. 1966. A third look at Minnesota's timber. USDA, Forest Service Resource Bull. NC-1, North Central Forest Experiment Station, St. Paul, Minn.

5. U.S. Department of Agriculture, Forest Service, 1961-1962. Timber resources of Aitkin, Carlton, Itasca, Koochiching, Lake and St. Louis counties. USDA, Forest Service, North Central For. Exp. Sta., St. Paul, Minn.

Table 2. - VOLUME OF GROWING STOCK ON COMMERCIAL FOREST LAND
BY SPECIES AND SIZE CLASS, 1961-62

County	Poletimber			Sawtimber		
	Softwood	Hardwood	Aspen	Softwood	Hardwood	Aspen
	-------------------Thousand Cords[1]----------------------					
Aitkin	853.0	1,756.7	1,311.2	349.2	1,150.6	121.1
Carlton	277.1	509.2	376.8	87.0	149.9	20.3
Itasca	3,058.8	2,564.8	4,445.0	1,960.0	1,029.8	693.7
Koochiching	6,207.7	1,535.7	3,261.4	1,878.3	745.9	642.0
Lake	3,052.1	1,857.4	1,787.0	1,761.1	436.3	702.8
St. Louis	7,150.1	3,894.4	7,691.5	4,475.6	941.3	1,010.8
Total	20,598.8	12,118.2	18,872.9	10,511.2	4,453.8	3,190.7

[1]Unpeeled total net volume of all merchantable trees 5.0 in. d.b.h.

	Total	Softwood	Other Hardwood	Aspen
Poletimber	51,589.9	20,598.8	12,118.2	18,872.9
Sawtimber	18,155.7	10,511.2	4,453.8	3,190.7
Total	69,745.6	31,110.0	16,572.0	22,063.6

Table 3. - GROWING STOCK VOLUME, ESTIMATED ANNUAL MANAGED HARVEST AND ACTUAL
REMOVALS FROM GROWING STOCK, 1960-62

	Softwood	Other Hardwood	Aspen	Total
	----------------------Thousand Cords----------------			
Volume of growing stock	31,110.0	16,572.0	22,063.6	69,745.6
Managed harvest	1,031.6	383.0	1,028.7	2,443.3
Cut from growing stock	494.9	49.9	316.7	861.5

Table 4.--PRICES PAID FOR PULPWOOD IN MINNESOTA, JANUARY THROUGH JUNE 1977[1]

Species	Price Range	Avg. Latest Prices	Amount Sold Within $.50 of Avg. Price
	$/Cord	$/Cord	%
F.O.B. CARS--LOCAL SHIPPING POINT, ROUGH BASIS			
Aspen	19.00-13.00	14.50	5
Balsam fir	30.50-28.00	29.50	70
Pine	30.50-28.00	28.50	89
Spruce	42.50-39.50	40.25	85
Tamarack	30.50-28.00	28.50	95
Birch	18.50-16.50	17.75	60
TRUCKED TO MILL, ROUGH BASIS			
Aspen	24.00-12.00	22.00	5
Balsam fir	38.00-32.00	32.00	95
Pine	31.50-	31.50	95
Spruce	48.00-42.00	42.50	95

[1]Private communication. Frank V. Ongaro, Commissioner, Department of Iron Range
Resources and Rehabilitation, Eveleth, Minn.
[2]Weighted average (mean) to closest $.25 of latest prices reported for the period.

Figure 1. Map of Minnesota showing major population and wood use
centers, 18 northern forested counties and 6-county resource area.

VIRGINIA, MINNESOTA

37.5 MMSF ANNUAL CAPACITY

LOGS & CHIPS (L & C) (PC = 202 + 1.17X)

FLAKES & CHIPS (F & C) (PC = 177 + 1.11X)

FLAKES (PC = 162 + 1.11X)

$ 178

4' X 8' X 24 - OPENING PRESS

75 MMSF

L & C (PC = 154 + 1.16X)

F & C (PC = 136 + 1.10X)

$ 178

4' X 16' X 24 - OPENING

112.5 MMSF

$ 178

L & C (PC = 138 + 1.16X)

F & C (PC = 123 + 1.09X)

4' X 24' X 24 - OPENING PRESS

150 MMSF

$ 178

L & C (PC = 134 + 1.14X)

F & C (PC = 122 + 1.07X)

8' X 24' X 16 - OPENING PRESS

PRODUCTION COST ($ / MSF, F.O.B. MILL)

WOOD COST ($ / ODT)

e 2.--Production cost (PC) vs wood cost (coeff · X), including taxes, profit
IRR), and selling expense (2%), for manufacture of 1/2-inch structural flakeboard,
basis.

171

PRODUCTION OPPORTUNITIES IN VERMONT

Lawrence D. Garrett[1]
Economist
Northeastern Forest Experiment Station
USDA Forest Service
Broomall, Pennsylvania

Abstract

Opportunities for production of structural flakeboard in Vermont exist both in the supply of raw material and marketing of the final product. An analysis of economic impact of such factors as raw material supply, plant size, and product market price indicate feasibility at existing factor input costs and product prices. The analysis also revealed profitability to be highly sensitive to raw material cost and final product price. Price increases from increased competition for wood resource for energy generation or paper products could cause significant increases in final product price. Market acceptance is strongly predicated on a competitive price line with 1/2-inch CDX plywood.

Introduction

Forests are a flexible resource. Technology exists to convert forest resources from any given location to a multiplicity of products; recreation, water, wildlife, forage, direct energy (boiler fuel), indirect fuels (gas), primary products (poles, pilings, lumber, timbers, veneer), secondary products (pallets, furniture, pulp and paper, chemicals), tertiary products (plastics, foods, fertilizers). The primary concern regarding use is economics, and more so a question of what use, rather than is it feasible. That is, the land manager must determine the maximum economic advantage of a particular wood resource given its alternative uses.

Past technology and supply and demand relationships have limited lower quality forest resource to lower value market products. Management philosophy has countered by emphasizing more intense management to develop veneer logs and high quality saw logs. In part, this has resulted in higher prices and consumption shifts to competitive materials. To counter, technology has been developed to turn low quality forest resource into higher quality products. Examples are: plywood, laminated beams, laminated ties, press board, and structural flakeboard.

Structural flakeboard can be produced from low quality hardwood and softwood resources which have limited marketability as either fuel wood or pulpwood (Fig. 1). New harvesting and processing technology, such as mechanized harvesters and shaping-lathe headrigs, provide the capability for increasing economic return from these otherwise non-marketable forest resource (1).

Structural Flakeboard Manufacture in Vermont

An evaluation of Vermont as a feasible location for a 150 MMSF per year plant reveals that both present supply and market factors will support the venture. The analysis also identifies manufacturing costs to be sensitive to plant size and cost of raw material. The latter factor is critical in Vermont due to proposed plans for pelletized fuel production and power generation from wood.

Market evaluations revealed that projected new home and business construction and renovations afford potential for regional plant expansion. Further, structural flakeboard produced in Vermont, New Hampshire, or Maine may have location preference to regional buyers, as contrasted with present plywood suppliers in Canada, the South, and the West Coast. However, critical elements of the construction market are product allegiance and strong price competition. Market acceptance of 1/2-inch structural flakeboard over 1/2-inch CDX plywood will require education, and lower pricing to permit market penetration.

Figure 2 illustrates the economic factors necessary for effective structural flakeboard manufacture in Vermont. The success of such a venture relies heavily on a readily available supply of raw material and a regional market with demonstrated capability of supporting a suitable market price. A closer look at raw material supply, harvesting costs, product price, and their influence on profitability will illustrate these findings.

Raw Material Supply

It is estimated that approximately 40 billion cubic feet of growing stock exist in all six New England states. Of this, 22 billion cubic feet are softwood and 18 billion cubic feet are hardwood (Table 1). Further, the regional growth-harvest relationships that have existed over the last two decades appear to be in favor of increased supply (1).

Vermont has 4.7 billion cubic feet of growing stock increasing at a rate of 2.3 percent annually (1). The forests have reflected changing agriculture cycles over time. The vast forests of the 18th Century were all but erased by the mid-to-late 19th Century due to growth in both the wood products and agriculture industries. Vast acreages were cleared, leaving only 30 percent of the area forested by 1870 (4). The early 20th Century brought competition from Midwest agriculture and the number of farms declined. Rapid expansion of succession forest types has resulted in the present large forest acreage, amounting to 80 percent of the total land mass.

Table 1. -- NET VOLUME OF TIMBER ON COMMERCIAL FOREST LAND IN NEW ENGLAND (1)

Species group	Source		Total
	Growing-stock trees	Cull trees	
Softwoods	20.2	2.0	22.2
Hardwoods	15.0	3.2	18.2
Total	35.2	5.2	40.4

[1]Stationed at Burlington, Vt.

day, Vermont's inventory of hardwoods comprise
rcent of total growing stock. Species compo-
n is predominantly hard maple, yellow birch,
maple, and beech. Softwood species repre-
d are primarily red and white pine, balsam fir,
e, and hemlock (Table 2).

mmercial forest land totals 4.4 million acres
percent of the state's land area (2). Ninety
nt of the commercial forests are owned by over
0 different private owners, split between
iduals (73,900), clubs and organizations
0), and corporations (700).

ty

e quality of Vermont's forests reflect poor
ng practices and lack of effective management.
of the forests are stocked with smaller pole
timber (Table 2). Further, quality appears
decreasing over time in most species groups

ality is the strongest drawback when assessing
nt's forests for traditional product markets.
of the hardwood resource is of a quality that
imited potential for high quality lumber or
r markets. This poses a critical question
rning future management. Needed intensive
ement to upgrade the quality of the resource
t be properly implemented without treatment of
quality material presently on the site. This
e accomplished either through public program-
uch as the forest improvement program (fip),
eating new markets such as structural flake-
, pulp, or energy.

Attitudes

rveys of Vermont and New Hampshire timberland
s indicate that people who sell timber
ally do so for businesslike reasons (5). That
roduct maturity, finances, and business
ing strongly relate to sales. People who do
ell do so for personal reasons, such as

claiming that attractive vistas would be spoiled.

The Vermont survey also indicated that 88 percent
of privately owned commercial forest land is owned
by people who could harvest their timber (5). This
totals to 3,517,300 acres or 3.8 billion cubic feet
of inventory and 84.8 million cubic feet of annual
net growth statewide. Further, the study revealed
that approximately 11,000 owners (14 percent) would
harvest some acreage within the next 10 years.

A 150 MMSF-capacity structural flakeboard plant
requires 159,750 oven dry tons annually, or 9.7
million cubic feet of oven dry equivalent re-
source. The above estimates would indicate that
plant needs could be supplied from current growth
with sufficient resource for a present annual cut
of 47 million cubic feet. This is further sup-
ported by Table 3 which demonstrates that growth
alone would exceed expected cuts plus input to
five structural flakeboard plants.

In general, central Vermont affords the least
supply constraints and minimum competition from
pulp companies in New York, Canada, and New Hamp-
shire. The reduced competition should minimize
raw material and hauling costs and still provide
direct access to coast markets in New York and
Boston.

Harvesting Costs

The primary harvest method used in Vermont is the
chainsaw-skidder system. During peak production
periods over 300 logging contractors are operating
statewide. The typical contractor operates one
skidder and two cutters. Production ranges from 20
to 40 MBF (40 to 80 cords) per week with an average
of 28 MBF (56 cords). In a pulpwood clearcut only
half the above ground volumes are removed for sale.

A mechanized harvesting system generally harvests
the above ground portion of the tree, which encom-
passes approximately 75 percent of total above
ground volume. The number of these machines in
Vermont presently varies between three and five.
The system uses a mechanical shearer, forwarder, and
chipper. Capital outlay for a complete system can

Table 2. -- VOLUME OF GROWING STOCK ON VERMONT'S COMMERCIAL FOREST LAND.

it and ounty	Forest-Land Area		Sawtimber Growing Stock	Pole Timber Growing Stock	Total Growing Stock	Growing Stock per Acre
	Commercial	Percent of Total Land Area				
	-----Thousand acres-----		-------------Million ft^3--------------			Ft^3
onia	291.3	74	150.6	151.7	302.3	1,037.7
	396.1	93	241.1	238.9	480.0	1,211.8
lin	236.9	56	89.0	101.8	190.8	805.4
Isle	--	--	--	--	--	--
lle	251.2	83	146.1	146.5	292.6	1,164.8
e	335.9	76	172.8	179.6	352.4	1,049.2
ns	339.0	74	181.6	183.5	365.1	1,076.9
ngton	361.3	80	202.0	202.8	404.8	1,120.4
hern Unit	2,211.7	75	1,183.2	1,204.8	2,388.0	1,079.7
on	285.8	57	143.6	132.9	276.5	967.4
ngton	370.7	86	206.3	193.6	399.9	1,078.7
enden	195.7	57	94.5	94.5	189.0	965.7
nd	444.9	75	237.1	225.7	462.8	1,040.2
am	428.5	85	242.2	231.1	473.]	1,104.5
or	492.6	80	279.1	261.6	540.7	1,097.6
hern Unit	2,218.2	74	1,202.8	1,139.4	2,342.2	1,055.9
l	4,429.9	75	2,386.0	2,344.2	4,730.2	1,067.8

vary between $250,000 and $500,000. It can harvest 5 acres a day. Yields with mechanized harvesters in Vermont average 35 to 45 cords per acre with cruise estimates ranging between 20 and 25 cords per acre (4).

Environmental attitudes and capital availability will slow transfers to mechanized total tree harvest systems in Vermont. Therefore, expected wood harvest costs for input to a flakeboard plant must represent both conventional and mechanized system costs. Tonnage yield per acre and harvest costs predicated on a 40 percent round wood and 60 chips harvest system appear realistic for a plant being established today.

Table 3.--PROJECTIONS OF NET ANNUAL GROWTH,
TIMBER REMOVAL, AND INVENTORY OF GROWING STOCK
AND SAWTIMBER ON COMMERCIAL FOREST LAND
IN VERMONT, 1973 to 2003 (2)[1]

	1973	1983	1993	2003
	(Inventory year)	Growing Stock		
	---------Million ft^3-----------			
Removals	47.8	68	97	127
Growth	106.6	122	139	154
Inventory	4,730.2	5,189	5,673	6,020

[1]Assumptions: commercial forest land will begin slow decrease after 1980; net annual growth as a percent of inventory is expected to increase from 2.3 to 2.6 %; timber removals will reflect expected timber-product demands and land-use changes.

Costs of raw material for a structural flakeboard plant will closely approximate current stumpage, harvest, and transfer costs for pulpwood. Pulpwood is the second major product harvested in Vermont, with over 140,000 cords marketed annually (Table 4).

As previously noted, a central Vermont plant location would minimize competition with pulp companies in New Hampshire, Vermont, and Canada. U. S. Forest Service projections indicate a gradual rise in demand for pulpwood in Vermont, but mostly in present high demand areas (2).

Although studies have not been completed to fully access the comparative economics of conventional and mechanized harvest costs in Vermont, reliable estimates by professional foresters and industry personnel are available.

The total cost of a cord of wood f.o.b. the mill site are estimated in Table 5 at $21.30 from a conventional system and $19.45 from a mechanized system. The labor costs of limbing and bucking are not necessary with the mechanized system and are shown to be zero. However, with hardwood, to gain maximum recovery and productivity per hour, a cost may be necessary to collapse the extreme branching in maple and birch. Estimated costs of screened chips f.o.b. plant site on an ovendry ton basis are $21.33 and $18.82, respectively.

Product Markets and Pricing

The Northeast has one of the largest building and renovation markets in the United States. Structural flakeboard would find extensive use in general construction for sheathing and underlayment and as decorative paneling, either exterior or interior. The sheathing market is now held primarily by CDX grade 1/2-inch plywood.

Plywood marketed in New England is shipped primarily from southern pine and western fir mills. New England based flakeboard plants would have to price below the current $250 to $270/MSF[1] price of 1/2-inch plywood to be competitive. In the current market, plywood prices reflect transfer costs of $20 to $30 from southern pine plants and $35 to $45 from western fir plants.

Market penetration pricing 10 to 15 percent below 1/2-inch agency grade CDX 4-5 ply plywood should gain product acceptance by building contractors. Pricing in the $220 to $230/MSF range f.o.b. New York and Boston markets would permit broker's fees and transfer costs of $10 to $20/MSF and a manufacturing cost of $200 to $210.

Production Costs and Profitability

The costs of manufacturing sheathing material is strongly related to variable input costs for wood, resin, and fuel. As related in Figures 2 and 3, these account for over 50 percent of total costs. Wood feedstock, at 16 percent of total costs, was found to severely impact plant profitability at prices above $27 per ovendry ton. A $14 rise per ovendry ton all but erases profit taking at a market price of $200/MSF. This demonstrates the critical aspect of necessary cost control in harvesting and transfer of round wood and chip inputs.

Anticipated marketability of structural flakeboard in New York and Boston markets would be competitive at 85 percent of the market price ($260) for agency grade CDX 1/2-inch plywood. A price below $197/MSF would not yield sufficient profit taking, whereas a price approaching $260 would probably limit builder and consumer acceptance.

[1]Point pricing estimates. Based on prices from wholesale shippers in Vermont, New York, and Connecticut (Feb. to Mar., 1978).

Table 4. -- TIMBER REMOVALS FROM GROWING STOCK AND SAWTIMBER ON COMMERCIAL FOREST LAND,
BY ITEMS, SOFTWOODS AND HARDWOODS, VERMONT, 1972.

Item	Growing Stock			Sawtimber		
	All species	Soft-woods	Hard-woods	All species	Soft-woods	Hard woods
	------------Thousand ft^3---------			---------Thousand bd. ft^1---------		
Roundwood products:						
Sawlogs	17,811	7,425	10,386	87,882	35,689	52,193
Veneer logs and bolts	1,055	--	1,055	4,711	--	4,711
Pulpwood	9,604	4,535	5,069	34,372	15,374	18,998
Piling	54	48	6	265	234	31
Poles	5	5	--	12	12	--
Posts	382	316	66	1,023	858	165
Other	2,575	689	1,886	6,538	1,869	4,669
Fuel wood	1,388	--	1,388	1,243	--	1,242
All products	32,874	13,018	19,856	136,046	54,036	82,010
Logging residues	8,189	2,689	5,500	15,608	4,498	11,110
Other removals	6,895	2,943	3,952	13,142	4,866	8,276
Total removals	47,958	18,650	29,308	164,796	63,400	101,396

[1] International 1/4-inch rule.

Table 5. -- COMPARATIVE COST ESTIMATES OF CONVENTIONAL AND MECHANIZED SYSTEMS.

Cost Elements	Systems	
	Conventional[1]	Mechanized[2]
Stumpage	$ 3.30	$ 2.50
Felling	1.10	1.65
Limbing and topping	2.20	.00
Bucking	3.30	.00
Skidding	4.40	4.95
Chipping	.00	3.95
Transport	7.00	6.40
Delivered cost	21.30	19.45
Bark and wood loss[3]	3.83	3.50
Debarking, chipping, screening	4.73	3.40
Total cost screened chips--cord basis	29.86	26.35
Oven dry ton basis	21.33	18.82

[1] Chainsaw felling, rubber tire or track vehicle skidding.

[2] Mechanized shearing, rubber tire forwarders, mobile chipper.

[3] Estimated at 18% of delivered cost (4).

References

1. Bones, James T. 1976. Potential sources of wood fiber in the Northeast. For. Prod. J. 26(2): 30-32.

2. Kingsley, Neal P., and Thomas W. Birch. 1977. The forest-land owners of New Hampshire and Vermont. U.S. Dep. Agric. For. Serv. Resour. Bull. NE-51. Northeast For. Exp. Stn., Broomall, Pa.

3. Koch, Peter. 1976. All systems to utilize hardwoods on pine sites can be combined. For. Prod. J. 103(13):24-27.

4. Rich, J. P. 1975. The feasibility of generating electricity in the State of Vermont using wood as a fuel--a study. J. P. R. Associates, Inc., Stow, Vt.

Figure 1.--Extensive forest areas in Vermont and New England are overstocked with small undesirable species of limited marketability.

Annual Wood Requirement
159,750 ODT

Investment
$29.30 MM

Market
150 MMSF, 1/2-inch

40% round wood

60% chips

	Wood Costs	Labor-Mater. Fuel	Plant & Overhead	Mkt.& Dist.	Taxes & Profit	Sales $/MSF, 1/2-inch
INPUTS						RETURNS
	$31 (16%)	$73 (37%)	$32 (16%)	$20 (10%)	$41 (21%)	$220.00
- Total -				Costs $197		Revenues $220.00

Figure 2.--Economic inputs and returns from a structural flakeboard manufacturing process, including 15% rate of return.

VERMONT LOCATION

Figure 3.--Production cost (PC) vs wood cost (coeff · X), including taxes, profit (15% IRR), and selling expense (5, 3, and 2%), for manufacture of 1/2-inch structural flakeboard, 1976 basis.

PRODUCTION OPPORTUNITIES IN LARAMIE, WYOMING

Donald C. Markstrom
Research Wood Technologist
Rocky Mountain Forest and Range Experiment Station
USDA Forest Service
Fort Collins, Colorado

Abstract

An environmentally desirable mode of operation for a plant at Laramie would be to utilize wood raw materials in the following order of priority: 1) forest residues removed with live sawtimber, 2) small roundwood thinnings removed with sawtimber in multiproduct sales or in designated small roundwood sales, and 3) sawmill residues. However, business economics favor this priority: 1) sawmill residues, 2) small roundwood from multiproduct sales, 3) forest residues from multiproduct sales, and 4) small roundwood from designated small roundwood sales. A Laramie plant should be economically feasible under certain circumstances. A plant with a production capacity of 112.5 MMSF, 12/-inch flakeboard per year should be more efficient than plants built to produce at levels of 37.5, 75 or 150 MMSF per year.

Introduction

Public and private groups are increasingly interested in the feasibility of producing both particleboard and structural flakeboard in the central Rocky Mountain region. Unused wood raw materials in the area include standing and down salvable dead trees, other small and unmerchantable roundwood, logging residues, and processing plant residues. Flakeboard production, probably the most compatible with existing forest industries in the central Rocky Mountains of any new forest-based industry, could provide outlets for roundwood that should be harvested to improve management of the area's forests. Use of unutilized wood resources would also enhance the area's general economic conditions.

The problem studied was whether a Laramie producer could derive sufficient advantage from his geographic location, available raw materials, production techniques, or production costs to compete in the flakeboard industry under existing or foreseeable conditions. Estimates of production costs, likely selling prices, and investment feasibility were developed for four hypothetical plants at Laramie.

Laramie was subjectively judged to be one of the most favorable sites in the area because there is a greater availability of forest and mill residues compared with other sites in the area. The City is also located on major transportation routes. Both the mainline of the Union Pacific Railroad and Interstate Highway 80 pass through Laramie, which would facilitate transportation of both raw materials to the manufacturing plant and the finished product to the market. The necessary professional and skilled workers could be attracted to Laramie because of well developed commercial, educational, cultural, and medical facilities and superior outdoor recreational opportunities for hunting, fishing, skiing, and hiking. Many people would consider Laramie a desirable place to live.

Availability of Wood Raw Materials

The types of wood raw material available are critical for flakeboard manufacture. Coarse sawmill residues, forest residues and small roundwood from either multiproduct sales or designated small roundwood sales are important because of different costs associated with each, and the available volume. The coarse sawmill residues are slabs, edgings, and trim from the live sawlogs. The forest residues are salvable standing and down dead material including mortality and logging residues. The small roundwood from multiproduct sales is that harvested in combination with sawlogs. Such roundwood on National Forest lands would come mostly from the Standard and Special components.[1] Small roundwood from designated small roundwood sales would come primarily from the Marginal component of National Forests.[1] The small roundwood on other ownerships would be found on land types similar to that of the National Forests. Considering these sources, the

---

[1] Standard component -- The component of the regulated forest land suitable and available for timber production on which crops of industrial wood can be grown and harvested with adequate protection of the forest resources under the usual provisions of the timber sale contract. Special component -- That part of the regulated forest land suitable and available for timber production which is recognized in the Multiple Use Plan as needing specially designed silvicultural treatment of the timber resource to achieve landscape or other key resource objectives. Marginal component -- A component of forest land suitable for regulated timber production but not currently available because of constraints from associated resource needs, high development costs and low product values, or absence of market for the species or product available.

imated volumes of residues and round-
d tributary to Laramie that are poten-
lly usable for flakeboard are as
lows:

Material	Volume[2]	
	thousand ft^3	thousand ODT
sting forest esidues[3]		
Standing dead	37,620	446
Down dead	217,282	2,575
Total dead	254,902	3,021
ging residues er year[3]	1,670	20
itional mortality er year[3]	10,427	124
rse sawmill residue er year[3]	4,219	50
11 roundwood per ear[4,5,6]	12,940	153

The volume of coarse sawmill residues
based on the production of sawmills
the area. The volume of small round-
d was determined from potential yields
the Medicine Bow, Routt, and Roosevelt
ional Forests. Data on potential
lds of materials from state, county,
 private lands were not available,
 volumes from these sources would be
nificant and could provide an addi-
nal supply "cushion".

An environmentally desirable mode of
ration for a particleboard plant at
amie would be to utilize wood raw
erials in the following order of
ority: 1) forest residues removed with
e sawtimber, 2) small roundwood thin-
gs removed either with sawtimber in
tiproduct sales or alone in designated
11 roundwood sales, and 3) coarse

———
[2] Calculated on the basis of 1 ft^3 =
7 oven dry pounds.

[3] Anderson, T. et al. 1975. Availa-
ity of wood raw materials at selected
ky Mountain locations. Unpublished
ort of a cooperative study made by
orado State University and the Rocky
ntain Forest and Range Experiment
tion, Fort Collins, Colo.

[4] USDA Forest Service. 1975. Timber
agement Plan. Medicine Bow National
est, Laramie, Wyo.

[5] USDA Forest Service. 1975. Timber
agement Plan. Routt National Forest,
amboat Springs, Colo.

sawmill residues. However, as shown
later in this report, economics favor this
priority: 1) coarse sawmill residues,
2) small roundwood in multiproduct sales,
3) forest residues from multiproduct sales,
and 4) small roundwood from designated
small roundwood sales.

Flakeboard performance may vary de-
pending upon the size, shape, and surface
quality of the flakes. Flakes produced
from drier dead material in some cases may
not be as uniform as those from living
material. Consequently, the performance
of flakeboard made with live and dead
materials may vary depending upon the mix.

The supply of materials available to
a Laramie flakeboard plant was projected
on the basis of sawmill production in the
tributary area. Live sawtimber, live
small roundwood, and forest residues could
be harvested together in multiproduct
sales and skidded, loaded, and hauled in
tree lengths to the sawmill and bucked
there for maximum product recovery. Small
roundwood, forest residues not suitable
for sawlogs, and tops from sawtimber would
be chipped into 2- to 3-inch length
chips. These chips, together with those
from the coarse sawmill residues, would
be shipped to the flakeboard plant in
chip vans.

The estimated annual volumes of wood
raw materials available for flakeboard
based on average sawmill production from
multiproduct sales would be as follows:

Material	Volume	
	thousand ft^3	ODT
Forest residues (all types)	3,485	41,290
Small roundwood	2,954	35,040
Coarse sawmill residues	4,253	50,440

An additional 90 thousand oven dry
tons of material from designated small
roundwood sales from the Marginal compon-
ent of the National Forests would also
be available annually.[4,5,6]

The gross volume of forest residues,
all types, was assumed to be 800 cubic
feet per acre. It was further assumed
that half of this volume would be sawed
into lumber and the other half chipped at
the sawmill. Only 75 percent of the gross
log volume was assumed to be suitable for
lumber and flakeboard chips combined.
Similarly, only 75 percent of the coarse
residues volume from sawed material was

———
[6] USDA Forest Service. 1975. Timber
Management Plan. Roosevelt National
Forest Extension, Fort Collins, Colo.

assumed to be suitable for chips. The cubic volume recovery of chips suitable for flakeboard production from roundwood was assumed to be 100 percent. The volume of small roundwood removed with sawlogs from multiproduct sales was considered to be in the same proportion as the volume of small roundwood to sawtimber shown in potential yield statements for the Standard and Special components of the Medicine Bow, Routt, and Roosevelt National Forests.[4,5,6]

Delivered Wood Costs

The delivered wood costs include all costs incurred in delivering woodchips to the plant site at Laramie. Costs were developed separately for forest residues, small roundwood in multiproduct sales and designated small roundwood sales, and for coarse sawmill residues (Table 1). Most of the costs were derived from Forest Service timber appraisal guides for the area. The cost of hauling chips from sawmills to the flakeboard plant were derived from a hauling cost equation developed by Withycombe (1). These derived costs were then adjusted for inflation.

Forest Residues

Forest residues were assumed to carry the same costs for felling and bucking, skidding, loading, overhead, and hauling as live sawtimber. Road costs, including maintenance, slash disposal, erosion control, and temporary development were assigned only to live sawtimber. On this basis, the total cost of forest residues delivered to the sawmill was $56.06/MBF The cost of chips delivered to the flakeboard plant was $44.11 per oven dry ton, assuming that 1.5 oven dry tons of chips are produced from each MBF of timber directly chipped and that .35 oven dry ton of chips is produced from coarse sawmill residues for each MBF sawed into lumber. The debarking and chipping cost was estimated to be $14.00/MBF, and the f.o.b. mill market value of chips produced from coarse sawmill residues was the same as for chips from live sawtimber--$7.50 per oven dry ton. Moisture content of chips made from partially dry residues was assumed to be 30 percent, based on oven dry weight.

Small Roundwood in Multiproduct

Felling, bucking, skidding, overhead, and hauling costs were assigned to small roundwood in multiproduct sales. Road--including maintenance--slash disposal, erosion control, and temporary development costs were charged to the live sawtimber. The moisture content of chips produced from green roundwood, when shipped from the sawmills to the flakeboard plant, was assumed to average 70 percent based

on oven dry weight. A total cost of chips of $42.18 per oven dry ton, delivered to the flakeboard plant, includes a cost of $28.81 for roundwood delivered to the sawmill, $7.00 for debarking and chipping at the sawmill, and $6.37 for hauling chips to the flakeboard plant.

Small Roundwood in Designated Small Roundwood Sales

Small roundwood in designated small roundwood sales would have to carry road maintenance, slash disposal, erosion control, and temporary development costs in addition to other logging costs shown for small roundwood in multiproduct sales. These additional costs were based on timber appraisal information for five sales on the Medicine Bow, Routt, and Roosevelt National Forests during 1975. A total cost of $47.51 per oven dry ton of chips delivered to the flakeboard plant includes an average cost of $34.14 for roundwood delivered to the sawmill, $7.00 for debarking and chipping at the sawmill, and $6.37 for hauling chips to the flakeboard plant. The above total costs do not include the cost of building primary roads into some presently unroaded areas. Building such roads would probably add another $5.00 to $7.00 per oven dry ton if their cost was entirely assigned to the timber cut.

Coarse Sawmill Residues from Live Sawlogs

The f.o.b. mill market value of pulpchips produced from live sawlogs at sawmills was estimated to be $7.50 per oven dry ton, based on an average pulpchip value of $9.00 per unit (2,400 ovendry pounds) during 1975.[3] An estimated total cost of $13.00 per ovendry ton delivered to the flakeboard plant includes $5.50 for hauling. The moisture conent of these chips was assumed to be 30 percent.

Cost of Manufacturing Flakeboard

Estimated costs of producing structural flakeboard at Laramie, Wyoming, range from approximately $126 to $205/MSF, 1/2-inch, excluding wood costs (Appendix D). These production costs depend largely on the size of the facility and to some extent on the cost of preprocessing roundwood and chips at the facility. The full cost, including wood costs, of producing structured flakeboard in different types and sizes of facilities are estimated in Figure 1. The product envisioned was a three-layer flakeboard with the faces of larger flakes and the cores of smaller flakes and other material produced from the chips.

Only a 40 percent flake/60 percent chip facility with press capacities of 37.5, 75, 112.5, and 150 MMSF, 1/2 inch was considered for Laramie, since furnish in chip form

Table 1. — ESTIMATED COST OF DIFFERENT WOOD MATERIALS TO PARTICLEBOARD PLANT.

e of Activity and Cost	Forest Residues	Small Roundwood, Multiproduct Sales	Small Roundwood, Small Roundwood Sales	Coarse Sawmill Residues- Live Sawlogs
	$/MBF[1]	$/Cord[2]	$/Cord[2]	$/ODT
ging				
ell and buck	11.00	5.98	5.98	--
kid	16.34	8.90	8.90	--
oad	5.48	2.98	2.98	--
verhead	7.47	3.74	3.74	--
aul	14.77	6.71	6.71	--
oad maintenance	--	--	.92	--
lash disposal	--	--	3.18	--
rosion control	--	--	.04	--
emporary development	--	--	1.19	--
tumpage	1.00	.50	.50	--
t to sawmill	56.06	28.81	34.14	7.50
ebarking and chipping	14.00	7.00	7.00	--
hips from sawed dead material	2.63	--	--	--
hip haul	8.92	6.37	6.37	5.50
ivered wood cost	81.61	42.18	47.51	13.00
t/ODT[3]	44.11	42.18	47.51	13.00

ch MBF of forest residues directly chipped yields about 1.50 ODT of chips; an addional 0.35 ODT of chips is realized from the coarse residues of each MBF sawn into mber. Thus, about 1.85 ODT of chips are recovered per MBT of forest sidues chipped.

ch cord chipped yields about 1.00 ODT of chips.

lowances for profit and risk were not included in delivered wood costs.

ld be the only wood material that ld be feasibly supplied to the plant. was assumed that facilities of each of different sizes could manufacture rd from 100 percent chips at the same t as from 40 percent flake/60 percent p mixture.

Total costs of producing structural keboard, including a composite capital t of 15 percent, was estimated for h size of facility, utilizing wood raw erials in the following priority: coarse sawmill residues, 2) forest idues, 3) small roundwood in multipduct sales, and 4) small roundwood in ignated small roundwood sales. This ority was based on both economic and ironmental considerations. The total duction and wood raw material costs wood raw material volumes required each size facility were:

Facility with 37.5 MMSF, 1/2-inch capay (per year) and 4' x 8' 24-opening

press.

A total production cost of $195.99 /MSF would be incurred using coarse sawmill residues at $13.00 per oven dry ton. Available coarse residues of 50,440 oven dry tons would be ample to supply the 38,650 oven dry tons required annually by the plant. The mixing of any other type of material with coarse sawmill residues would obviously increase the total production costs per MSF.

2. Facility with 75 MMSF, 1/2-inch capacity (per year) and 4' x 16' 24-opening press.

A total production cost of $168.14 /MSF would be incurred using 76,500 oven dry tons at $23.00 per oven dry ton. The chip mix would consist of the following:

Wood raw material	Annual volume	Cost/ODT
	ODT	$
Coarse sawmill residues	50,440	13.00
Forest residues	26,060	44.11

The entire available supply of coarse sawmill residues would be utilized, plus about half as much forest residues.

3. Facility with 112.5 MMSF, 1/2-inch capacity (per year) and 4' x 24' 24-opening press.

A total production cost of $284/MSF would result from using 114,450 oven dry tons at $30.02 per oven dry ton. The chip mix would consist of the following:

Wood raw material	Annual volume	Cost/ODT
	ODT	$
Coarse sawmill residues	50,440	13.00
Forest residues	41,290	44.11
Small roundwood from multi-product sales	22,720	42.18

The entire available supply of both coarse sawmill and forest residues would be utilized, with about a fifth of the requirement being supplied by small roundwood.

4. Facility with 150 MMSF, 1/2-inch capacity (per year) and 8' x 24' 16-opening press.

A total production cost of $165.11 /MSF would result from using 149,600 oven dry tons at $33.69 per oven dry ton. The chip mix would consist of the following:

Wood raw material	Annual volume	Cost/ODT
	ODT	$
Coarse sawmill residues	50,440	13.00
Forest residues	41,290	44.11
Small roundwood from multi-product sales	35,040	42.18
Small roundwood from designated small roundwood sales	22,830	47.51

The entire available supply of coarse sawmill residues, forest residues, and small roundwood in multiproduct sales

would be utilized, plus almost a sixth of the requirement coming from small roundwood sales.

Likely Market Value of Structural Flakeboard

Development of high volume markets for structural flakeboard will require expanded use of this type product in floor, roof, and wall sheathing; combination sheathing-siding; and siding. To compete with plywood, flakeboard will have to be sold at or below the price of comparable plywood. The most comparable plywood sheathing product on the market today is CDX, 1/2-inch thickness.

Two major market areas were originally considered for study as potential outlets for Laramie-produced flakeboard--Omaha and Denver. Omaha was selected as the prime market area after considering both the average price paid by distributors for CDX, 1/2 inch plywood, and the freight cost for shipping 1/2-inch structural flakeboard from Laramie. Denver was not selected because of the low average price of the plywood. The average delivered price for CDX plywood, f.o.b. Omaha, was about $198/MSF, 1/2 inch in 1976. The estimated price of structural flakeboard from Laramie would range from $178 to $198/MSF, 1/2 inch f.o.b. Omaha. Since the 1976 freight cost would have been about $24/MSF, 1/2-ich from Laramie to Omaha, a residual f.o.b. plant value would have then ranged from about $154 to $174.

Conclusions

The financial analysis indicated that under the assumptions used a Laramie facility built to produce 112.5 MMSF, 1/2 inch basis of flakeboard per year would be more economically efficient than a plant to produce at leavels of 37.5, 75, or 150 MMSF, 1/2 inch. Total production costs and the costs of wood materials for each facility size are estimated as follows:

Plant size	Total production cost	Cost of wood raw materials
MMSF,1/2 inch	$/MSF	ODT
37.5	195.99	13.00
75	168.14	23.60
112.5	162.84	30.02
150	165.11	33.69

The smallest plant size is least efficient, even though its cost of wood raw materials is lowest. The economies of scale begin to be offset by the higher cost of wood raw materials, however, as forest residues and roundwood become a greater proportion of the necessary raw material mix for plants of larger size.

Other possible cost factors are illus-
ed by the example that the total
uction costs for the 150   MMSF,
inch facility would rise from $165.11
170.92/MSF if wood costs increased
1 per cord or oven dry ton to
r primary road construction for
gnated small roundwood sales.

Total production costs for the 75,
5, and 150   MMSF (1/2") plants ap-
to be marginally within the range
976 f.o.b. plant values ($154 to
) estimated for flakeboard sold in

Omaha. The total production cost of
$195.99 for the 37.5 MMSF plant,
however, greatly exceeds the maximum
estimated plant market value.

Reference

1. Withycombe, R. 1975. The outlook
for particleboard manufacture in the
Northern Rocky Mountain region. USDA
For. Serv. Gen. Tech. Rep. INT-21.
Intermt. For. and Range Exp. Stn.,
Ogden, Utah.
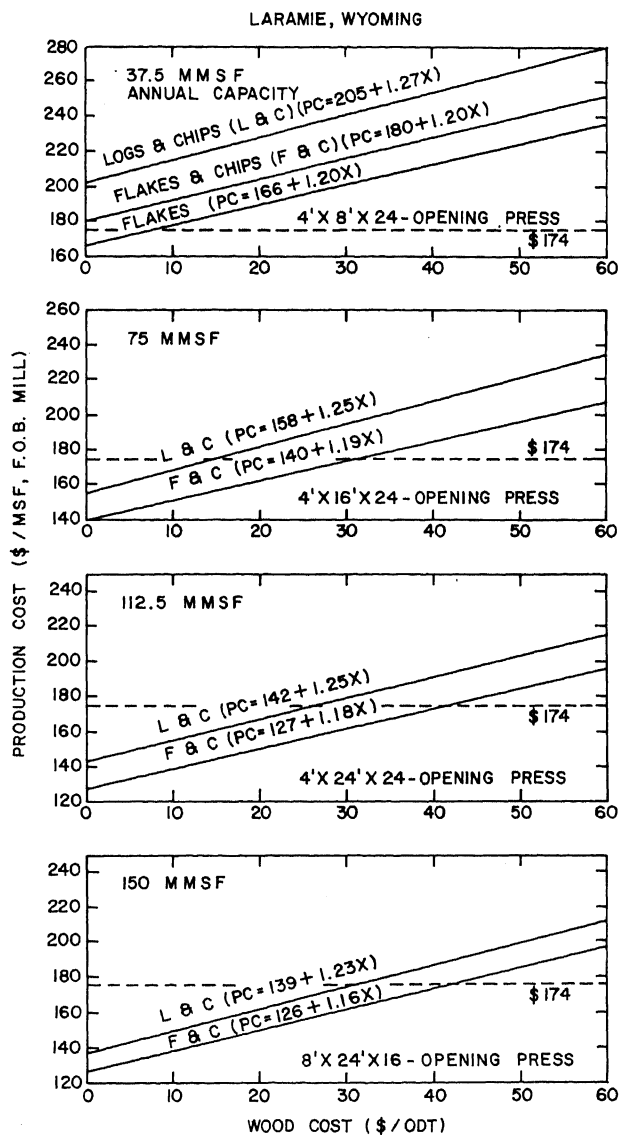
re 1.--Production cost (PC) vs wood cost (coeff · X), including taxes, profit
 IRR), and selling expense (5, 3, and 2%), for manufacture of 1/2-inch structural
eboard, 1976 basis.

PRODUCTION OPPORTUNITIES IN THE NORTHERN ROCKIES

Richard Withycombe[1]
University of Montana
Missoula, Montana

Abstract

The northern Rocky Mountain region is
heavily forested with mixed conifers, and
contains large volumes of forest residues.
Two areas have been selected as typical of
the region: Western Montana and South-
eastern Idaho. The residues in western
Montana are dead or cull material that will
be available as an adjunct to logging for
sawlogs, while the material in south-
eastern Idaho consists primarily of lodge-
pole pine recently killed by bark beetle
infestation.

The costs of harvesting the forest
residues are estimated at $22.38 per oven-
dry ton in western Montana, and $29.91 per
ovendry ton in southeast Idaho. The costs
of converting the material to structural
flakeboard is not significantly different
from the costs found for other potential
manufacturing sites in the United States,
but the high transportation costs to the
primary marketing areas make the manufac-
ture of structural flakeboard economically
infeasible at present prices. A sustained
price increase of about 10 percent above
1976 prices (excluding inflation) would be
required before a flakeboard plant would be
considered feasible in the Northern
Rockies.

Introduction

The northern Rocky Mountain region is a
mountainous area about 300 miles wide and
600 miles long that lies in a broad band
from just south of Yellowstone National
Park, north to Canada. To the south there
are large, high plateaus and gently rolling
hills, while to the north the land is steep
and rugged. Most of the area is heavily
forested with mixed conifers, with lodge-
pole pine, Douglas fir, and western larch
being the dominant commercial species.

Two sites within this area have been
selected representative of the whole re-
gion: St. Anthony, Idaho, in southeast
Idaho adjacent to Yellowstone Park, and
Missoula, Montana, in the northern moun-
tains.[2] The forest residues available to

a structural flakeboard plant in Missoula
will consist primarily of dead or down
timber and small stems that will become
available as an adjunct to logging for
veneer and sawlogs. The wood will be a
mixture of lodgepole pine, Douglas fir,
and western larch, with some alpine fir.
St. Anthony is adjacent to large tracts
of dead lodgepole pine, the result of a
recent infestation of mountain pine bark
beetle. The trees are mostly standing
dead, with heavy concentrations in many
areas. Some of this material will become
available as an adjunct of normal logging
operations, but most would be harvested
as sales of dead timber. Most of the
dead wood is sound, but has large checks
which make portions of it unsuitable for
lumber or veneer use.

Residue Volumes

Volumes of forest residues in western
Montana have been estimated[3] based on cur-
rent harvesting plans for sawlogs. The
actual volumes of residues will vary con-
siderably according to what part of the
total biomass is considered as available
residues. Only stems, or parts of them,
that are sound enough and large enough
to pick up and haul on a log truck have
been considered for this analysis. Based
on the current average of about 100,000
acres per year in western Montana that is
harvested for sawlogs, there should be
about 75 to 120 million cubic feet of
useable forest residues generated per
year. That is enough fiber to supply
from 10 to 15 structural flakeboard
plants, each one producing 150 million
square feet of one-half inch flakeboard
per year. The estimates of the available
volumes of forest residues are subject to
considerable error, but there is no doubt
that there is a sufficient volume to fur-
nish several flakeboard plants.

The forest residues in southeastern
[Idaho] consist primarily of standing dead
[lod]gepole pine, the result of an epidemic
[infe]station of mountain pine bark beetle.
[The]re is an estimated 668 million cubic
[fee]t of dead timber in the area. The
[Tar]ghee National Forest would prefer to
[har]vest this timber within the next 15
[yea]rs, which would make about 50 million
[cub]ic feet per year available for
[pro]ducts.

[N]ot all of the estimated total volumes
[in] either area would actually be available
[for] production of flakeboard. Much of the
[mat]erial in both regions is in remote
[are]as far from roads. A portion of those
[are]as may eventually be classified as wil-
[der]ness, or be otherwise reserved from
[har]vest. The estimates for western
[Mon]tana should be reduced by about one-
[thi]rd, and those for the Targhee should
[be] reduced by as much as one-half to
[acc]ount for those areas that may not be
[har]vested.

[T]here is some current utilization of
[for]est residues in both areas. At times
[whe]n the national (or international) mar-
[ket] for pulp chips is strong, and other
[supp]lies are short, pulp chips are pro-
[duce]d from dead timber, but most of the
[time] the cost of harvesting and shipping
[the] chips exceeds their market value, so
[tha]t there is little collection of
[for]est residues for chips. House logs
[are] produced throughout the area, and
[the]re is a constant but relatively small
[mar]ket for posts and poles from dead or
[ful]l timber. Considerable volumes of
[rece]ntly dead lodgepole are sawn for
[fuel]; lumber may be obtained from them,
[with] much of the stem going to pulp
[chip]s.

[E]ven after reducing the estimated total
[volu]mes of forest residues by 30 to 50
[perc]ent because of inaccessibility, and a
[furt]her 10 to 20 percent for competing
[use]s, there still remains about 50 mil-
[lion] cubic feet per year in western
[Mon]tana, and about 20 million cubic feet
[per] year in Southeastern Idaho, or enough
[to s]upply eight large flakeboard plants
[in] the two areas combined.

Harvesting Costs

[I]n estimating the harvesting costs for
[wes]tern Montana, it has been assumed that
[the] residue would be harvested along with
[norm]al logging operations, so that all
[cos]ts of road building, road maintenance,
[and] slash treatment will be borne by the
[saw] and veneer logs. The only costs al-
[loca]ted to the residues will be the costs
[of fe]lling, yarding, loading, transporta-
[tion], and chipping. It is further as-
[sume]d that all residues will be hauled as
[logs] to a central chipping facility,
[rath]er than be chipped in the woods.
[Prev]ious experience has indicated that in
[the] generally steep terrain of western

Montana a central chipping facility re-
sults in a lower total cost than does
in-woods chipping by portable chippers.

The harvesting costs for western
Montana are estimated at $22.38 per oven
dry ton. The estimate was based on
"Timber Production Costs" published by
the Bureau of Land Management. The as-
sumptions and the calculation of the
estimated costs are shown in Table 1.

The harvesting of dead lodgepole in
the St. Anthony area could be handled
by conventional logging techniques, but
the costs would tend to be somewhat
higher than for Western Montana because
of the small stem size. The generally
flat terrain and small stem size make
the use of mechanical harvesting tech-
niques feasible. Table 2 shows a pro-
jected cost of $29.91 per ovendry ton,
based on the use of a feller buncher with
delimbing attachments, a grapple skidder,
and a portable debarking and chipping
machine.

In-woods chipping appears to cost
somewhat more than a central chipper per
ton of chipped wood, but there are some
offsetting costs savings. The transporta-
tion cost has been estimated as 70 per-
cent of that required to haul logs be-
cause of the greater bulk density of
the chips. (This assumes that the road
system can accommodate the chip truck.)
In-woods chipping eliminates the need
for bark disposal at a central chipper,
and should also result in more complete
utilization of the available fiber,
since small pieces and tops that would
not be hauled on a truck can be chipped.
Slash treatment costs have also been
reduced in the estimated cost of har-
vesting by mechanical harvester and in-
woods chipping. The dry, brittle lodge-
pole branches tend nearly to disappear
after they have been snapped off by the
delimber and trampled a bit by the
skidder, and the in-woods chipper eli-
minates cull logs or short tops that
would be left as a result of conven-
tional logging. The end result is a
remarkably clean site that will require
very little post-harvesting effort.

Production Costs for Structural Flakeboard

The costs of structural flakeboard
production[4] (exclusive of wood cost) are
nearly the same for all sites in the
northern Rocky Mountain region. The cost

---

[4]Derived from the computer model devel-
oped by George Harpole. See "Overview of
Structural Flakeboard Production Costs," in
these proceedings.

of plant and equipment, land, the cost of capital, and taxes are relatively uniform across the United States. There are, however, some significant differences between areas in the costs of labor, energy, and wood.

The cost of labor in the northern Rocky Mountains is about 10 percent lower than for similar jobs in the west coast states, but is much higher than the south or east. Energy costs (both electrical and fuel oil) are slightly lower than the west coast, and much less than the south or east. The total production costs, excluding wood, are about the same as for the west coast sites, but are about 15 percent to 24 percent higher than the east and south.

Figures 1 and 2 show total production cost as a function of the wood cost. The two lines on each chart represent two of the assumed mixes of raw material, with 40 percent logs and 60 percent chips, or 40 percent flakes and 60 percent chips. The line for the mix using logs is higher in all cases because of the greater cost for chipping and drying the log furnish. Total production costs include state and Federal taxes (51.5 percent), profit (15 percent IRR), and selling expense (5, 3, and 2 percent). The economics of scale obtained by the greater press size is apparent.

The estimated sales price at the mill is shown as a horizontal dashed line. The price was derived by assuming a primary market in the Bismark, North Dakota, area for both mill sites. The average 1976 price of $196/MSF for 1/2-inch CDX plywood was reduced by the shipping charges to obtain f.o.b. mill prices of $145/MSF, 1/2-inch/MSF for western Montana.

The break-even cost is shown (where positive) on each figure. In all cases, the break-even cost is significantly below the anticipated cost of harvesting forest residues, so that structural flakeboard production in the northern Rocky Mountain area does not appear to be economically feasible. In order to be feasible, with the estimated wood costs for the two sites, a sales price of $160 f.o.b. mill for St. Anthony, or $153 for the northern Rocky Mountains is required. These represent the break-even prices for the larger press size and a furnish mixture of 40 percent flakes and 60 percent chips. The break-even prices are about 10 percent to 14 percent higher than the 1976 prices.

The primary reason for the dim outlook for structural flakeboard production in the northern Rocky Mountain area is, of course, the cost of transportation to distant markets. Of the sixteen sites selected as representative of probable manufacturing sites in the United States,

western Montana has the lowest price f.o.b. mill after adjusting for transportation, and St. Anthony is the third lowest. The effects of distance are even more severe when structural flakeboard is considered a competitor of plywood. If both can be sold at the same price at their destination, the greater weight of flakeboard will necessitate a lower price at the mill; and the difference will be greater for greater distances. With Bismark the assumed market for flakeboard from western Montana, the difference in transportation costs of flakeboard and plywood is $7/MSF, 1/2-inch basis. For shipment to the East Coast, the difference is $10. (This assumes weights of 1,873 lb/MSF for flakeboard and 1,500 lb/MSF for plywood.)

A small structural flakeboard mill serving the nearby markets would escape the high transportation costs, but the costs of production for a small plant make this alternative appear inadvisable.

References

1. Fulkema, M.P. 1977. Evaluation of Kockumus 880 "Tree-King" feller-buncher. Tech. Rep. No. TR-13. For. Eng. Res. Inst. Can., Vancouver, B.C.

2. Legault, R., and L.H. Powell. 1975. Evaluation of FMC 200 BG grapple skidder. Tech. Rep. No. TR-1. For. Eng. Res. Inst. Can., Vancouver, B.C.

3. Sampson, G.R., H.M. Worth, and D.M. Donnelly. 1974. Demonstration test of in-woods pulp chip production in the Four Corners' region. USDA For. Serv. Res. Pap. RM 125. Rocky Mtn. For. Range Exp. Stn., For Collins, Colo.

4. U.S. Department of the Interior, Bureau of Land Management. 1977. Timber production costs schedule 20. U.S. Dep. Int., BLM, Oregon State Office, Portland, Ore.

Table 1. - RESIDUE HARVESTING COST ESTIMATES--WESTERN MONTANA

	Cost
	$/MBF
Falling and bucking[1]	7.60
Yarding and loading[2]	7.35
Transportation[3]	19.81
Cost to mill	34.76
Cost per ODT @1 MBF = 2 ODT	17.38
Debark and chip	5.00
Net cost	22.38

[1] Average DBH = 12 in; percent top loss = 20% (4).

[2] Average volume per 16-foot log = 80 bd. ft ;
   average yarding distance = 500 ft ;
   yarding method, tractor (4).

[3] Hard surface distance = 30 mi ; gravel surface distance = 10 mi ;
   dirt surface distance = 5 mi ; rate of rise and fall = 10-20% (4).

Table 2. - RESIDUE HARVESTING COST ESTIMATES--ST. ANTHONY, IDAHO, AREA

	Cost
	$/MBF
Fall and limb (mechanical harvester)[1]	5.78
Yard (grapple skidder)[2]	5.06
Chip[3]	9.90
Transportation[4]	6.93
Basic cost	27.67
Road maintenance[5]	1.09
Fire protection[6]	.40
Fuel treatment[7]	.75
Total cost	29.91

Economic life = 14,000 hr ; utilization = 70%; maintenance cost = $17/hr ;
   productivity = 800 ft³/hr   (1).

Economic life = 12,000 hr ; utilization = 70%; maintenance cost = $15/hr ;
   productivity = 800 ft³/hr   (2).

Reference (3).

Calculated as 70% of log transportation costs, Table 1.

Based on 10 mi gravel and 5 mi dirt.

Based on small scale, trailer with mounted pump (1).

Based on machine piling and burning, reduced by one-half to account for low
   residue volume. Assumed 40 ODT per harvested acre (1).
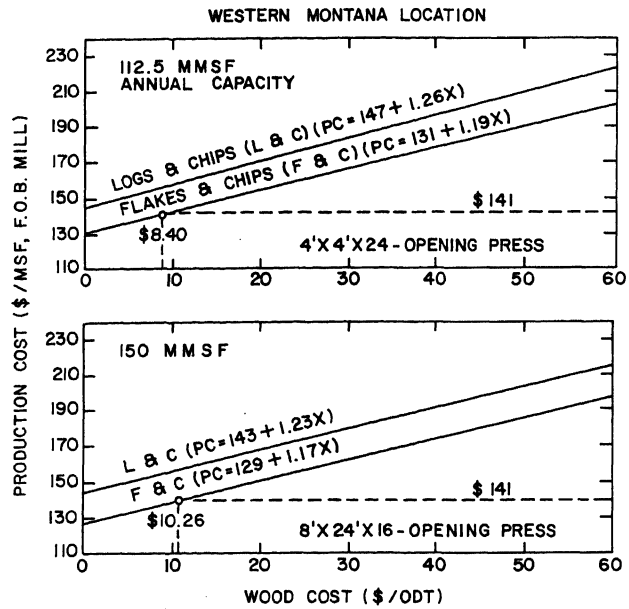
Figure 1.--Production cost (PC) vs wood cost (coeff · X), including taxes, profit (15% IRR), and selling expense (5, 3, and 2%), for manufacture of 1/2-inch struct flakeboard, 1976 basis.
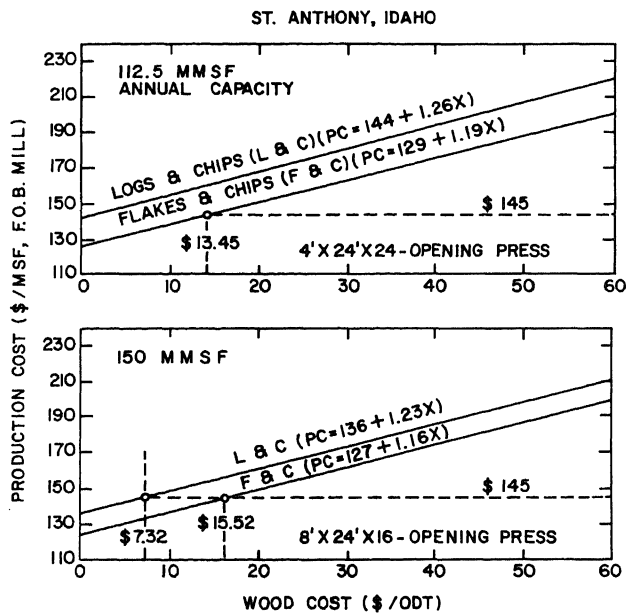
Figure 2.--Production cost (PC) vs wood cost (coeff · X), including taxes, profit (15% IRR), and selling expense (5, 3, and 2%), for manufacture of 1/2-inch structu flakeboard, 1976 basis.

PRODUCTION OPPORTUNITIES IN THE PACIFIC NORTHWEST

Thomas C. Adams
Research Economist
Pacific Northwest Forest & Range Experiment Station
USDA Forest Service
Portland, Oregon

Abstract

Feasibility of structural flakeboard manufacture in Washington and Oregon was explored as part of the national program to develop a new product that could help meet rising demand for future building products. The raw material would come chiefly from forest residue, little-used species, and small or defective trees.

Sufficient raw material now exists in Washington and Oregon for a number of structural flakeboard plants, but collection and processing the raw material to uniform clean flakes at a plant site would be costly. Forest industries are well developed in these two States and could easily expand into production of structural flakeboard. It is, however, unlikely that structural flakeboard production from the Pacific Northwest can compete with the same type of board produced closer to distant markets, nor with conventional plywood in western markets.

Introduction

A large share of the timber harvest in Washington and Oregon comes from old-growth forests, with some of the Nation's highest levels of logging residue. In addition, both States contain large areas of lodgepole pine and associated species killed by recent forest insect epidemics. Other types of forest residue include natural mortality, little-used species (chiefly hardwoods), and undesirable growing stock trees. The Forest Residues Program at the Pacific Northwest Forest and Range Experiment Station is looking for ways to reduce forest residue by treatment, improved logging systems, and increased utilization. Structural flakeboard is one class of product that can be made from forest residue (1,4,5,6). This study analyzes the economic feasibility of structural flakeboard production at three representative locations: Longview, Washington, and Medford and La Grande, Oregon.

Structural flakeboard is composed of thin wafers or flakes approximately 1/2 inches long. These produce a building board panel intended to be competitive in strength qualities to sheathing grades of softwood plywood. If structural flakeboard can be produced at a lower cost than plywood, it should be able to help stretch the Nation's raw material supply in the long-term, growing housing market (3,8).

Washington and Oregon are strongly oriented toward the forest industries, and these States already have the related technology, managerial ability, and skilled labor force employed in conventional particleboard manufacture. Existing particleboard operations are well integrated with other forest industries in matters of raw material supply and end-product sales functions and without much difficulty could expand into production of structural flakeboard. The main question is one of economics--whether or not structural flakeboard from the Pacific Northwest can compete with the same type of board produced closer to distant markets, chiefly in the Midwest and Eastern States, or whether it can compete with conventional plywood in western markets.

Quantity and Availability of Forest Residue Materials

The greatest total volume of forest residue, as well as volumes per acre, occur as logging residue associated with clearcutting in the Douglas-fir region of western Washington and western Oregon. Howard (2) estimated this annual production, including limbwood, to be 465 million cubic feet for 1969, a fairly typical year. Average net volume of logging residue was 1,344 cubic feet per acre on private lands, 3,153 cubic feet per acre on National Forest lands, and 2,054 cubic feet per acre on other public lands (Table 1). These volumes do not include pieces less than 4 inches in diameter outside bark and 4 feet in length.

Similarly, in eastern Washington and eastern Oregon, Howard estimated the logging residue from all types of logging to be 93 million cubic feet, averaging 376 cubic feet per acre on private lands and 312 cubic feet per acre on public lands.

In addition, there is an estimated 227 million cubic feet of standing dead timber, mostly lodgepole pine, killed from 1968 through 1977 by the mountain pine beetle in eastern Washington and eastern Oregon. Most of this is in the Blue Mountains of northeastern Oregon.

Other types of forest residue, not associated with logging, such as normal mortality, hardwoods, and undesirable growing stock trees, are mostly widely scattered and are not considered to be feasible sources for utilization except

Table 1. - NET VOLUME OF LOGGING RESIDUE IN
WASHINGTON AND OREGON, 1969.[1]

	Total Volume	Bucked Log	Breakage	Full Tree or Top	Limbwood	Slabs and Splinters
	----------------------------Million ft^3----------------------------					
Douglas-fir region						
National Forest	142.8	75.7	46.0	12.8	1.8	6.5
Other public	102.7	48.8	27.1	17.9	1.4	7.5
Private	219.8	31.4	103.4	55.9	2.6	26.6
	465.3	156.0	176.4	86.6	5.8	40.6
Ponderosa pine region						
National Forest[2]	64.0	14.4	11.7	33.4	4.3	0.2
Private	29.0	2.3	8.5	14.9	1.9	1.5
	93.0	16.7	20.2	48.3	6.2	1.7
Total[3]	558.3	172.6	196.6	134.9	11.9	42.2

[1] Source: Developed from Table 15 of Howard (2).

[2] Includes some land owned or administered by other public agencies.

[3] Data may not add to totals because of rounding.

as they can be taken out along with sound material in regular harvest operations.

Quantities of annual logging residue in three geographic areas were estimated, based on the relation of log harvest to logging residue in the base year 1969, for which logging residue data are available. These areas included:

1. Clark, Cowlitz, Lewis, and Wahkiakum Counties, Washington, and Columbia County, Oregon (potential utilization center Longview, Washington);

2. Josephine and Jackson Counties, Oregon (potential utilization center Medford, Oregon); and

3. Umatilla, Union, Baker, and portions of Grant and Wallowa Counties, Oregon (potential utilization center La Grande, Oregon).

The above estimates include only the material classified by Howard as 41 percent or more chippable and were reduced by 10 percent to allow for material that would be too scattered or too far from a potential landing to be economically harvested.

Results are expressed in terms of amounts within a hauling distance of either 40 or 60 miles for Longview and Medford areas, and 50 or 80 miles for the La Grande area in eastern Oregon (Table 2). These hauling distances reflect the radius within which a prospective plant might plan to obtain the majority of its raw material. Actual plant locations might be anywhere within the corresponding geographic area. Where amounts shown are insufficient to support one structural flakeboard plant, additional raw material would have to come from green timber, which could include sanitation cuttings, fire salvage, and silviculture thinnings.

Of the 227 million cubic foot backlog of insect-killed timber in eastern Washington and eastern Oregon, the three National Forests most directly concerned (Umatilla, Malheur, and Wallowa-Whitman) estimate that up to 40 percent or 90.8 million cubic feet are not likely to be harvested in 20 years, because of such things as lack of roads, small tree size, low volumes per acre, or high harvest costs. This leaves 136.2 million cubic feet potentially available for harvest, which amounts to 6.8 million cubic feet annually for 20 years.

Table 2. - LOGGING RESIDUE AND INSECT-KILLED TIMBER
AVAILABLE ANNUALLY IN THREE GEOGRAPHIC AREAS,
AND NUMBER OF POTENTIAL STRUCTURAL FLAKEBOARD PLANTS.[1]

Residue Type and Geographic Area	Available Annual Amount	Number of Potential Flakeboard Plants (37.5 MMSF, 1/2-inch)
	Million ft^3	
Logging residue		
Southwestern Washington (Longview)		
40 mile radius	13.3	4.2
60 mile radius	30.0	9.5
Southern Oregon (Medford)		
40 mile radius	5.9	1.9
60 mile radius	13.2	4.2
Eastern Oregon (La Grande)		
50 mile radius	2.9	0.9
80 mile radius	7.3	2.2
Insect-killed timber		
Eastern Oregon (La Grande)		
50 mile radius	2.7	0.8
80 mile radius	6.8	2.1

Source: Developed by Forest Residues Research, Development, and Application Program, Pacific Northwest Forest and Range Experiment Station, U.S. Forest Service, Portland, Oregon.

Utilization of forest residue for structural flakeboard must be able to meet the competition from other potential products such as lumber, veneer, pulpwood chips, and fuel for energy. Except for energy, these products tend to have a higher value, and hence would probably be able to bid the raw material away from structural flakeboard manufacture. Thus, physical availability of forest residue in the forest is not the same as economic availability to a given manufacturing plant.

Economic availability of forest residue material for structural flakeboard depends on such things as distance to a potential utilization center, road accessibility, volume per acre, contractual arrangements with the landowner, and the residue material's competitive value for a variety of potential products.

New manufacturing plants need some kind of assured raw material supply for their planned amortization period, usually around 10 to 20 years. As with regular timber sales on the National Forests, it may be sufficient for a large, strong firm that raw material will continue to be competitively available. It may, however, be difficult for a smaller firm to obtain sufficient logging residue from a large number of public timber sales to others.

Costs of Harvesting

Costs of harvesting forest residue-type materials were developed using the U.S. Forest Service, Region Six Appraisal Handbook as a guide (Table 3). Firmwood scaling defect, based on potential recovery of flakes rather than lumber or veneer, was estimated at 20 percent in the Longview and Medford areas, and 10 percent in the La Grande area.

Stumpage cost for potential flake-

	Longview, Wash.	Medford, Ore.	La Grande, Ore.
	---------------$/fbm net firmwood scale-------------		
Felling and bucking[2]	--	--	10.71
Yarding	17.56	17.56	15.98
Loading	4.46	4.46	4.58
Overhead	2.48	2.48	3.97
Depreciation	2.87	2.87	2.27
Woods fire protection	.43	.43	.47
Transportation			
40 miles	21.22	21.22	--
50 miles	--	--	32.92
	49.02	49.02	70.90
Differential for low volume per acre (Medford), and deterioration prior to harvest (La Grande), 10%	--	4.90	7.09
Stumpage	.50	.50	.50
	49.52	54.42	78.49
Profit and risk allowance, 10%	4.95	5.44	7.85
	54.47	59.86	86.34
Equivalent cost per cunit (@5.5 fbm/ft^3)	(29.93)	(32.89)	--
(@5 fbm/ft^3)	--	--	(43.17)
Cost per oven dry ton (@78.1363 ft^3/ODT	(23.39)	(25.70)	--
(@82.1433 ft^3/ODT	--	--	(35.46)

[1]Developed from Region 6 appraisal handbook (7).

[2]Material near Longview and Medford is assumed to be logging residue requiring little
or no bucking; material near La Grande is assumed to be mostly standing dead trees.

board logs was estimated at $0.50 per
thousand board feet in all areas, recog-
nizing that some logs would have a higher
value for other products and be assigned
a higher stumpage value. A profit and
risk allowance of 10 percent was also
applied, on the basis that the largest
share of wood supply would probably be
purchased wood.

The resulting costs were converted to
costs per cunit at 5.5 board feet per
cubic foot (Longview and Medford areas)
and 5 board feet per cubic foot (La Grande
area). Costs per oven dry ton were then

calculated at 78.1363 cubic feet per oven
dry ton (Longview and Medford areas) and
82.1433 cubic feet per oven dry ton (La
Grande area). The resulting costs were
then rounded to $23, $26, and $35 per
oven dry ton, respectively, for de-
livered wood in the three areas.

These costs are our best estimate of
average costs under realistic operating
conditions. Actual costs of harvesting
small pieces, as from tops and limbs,
could exceed these amounts by a wide
margin if harvesting is by regular log-
ging equipment. Chipping or flaking of

Table 4. - ESTIMATED COSTS OF PRODUCTION FOR STRUCTURAL FLAKEBOARD,
INCLUDING WOOD COSTS, AT LONGVIEW, WASHINGTON, AND
MEDFORD AND LA GRANDE, OREGON, 1976.[1]

te and od Supply	Annual Production and Press Size			
	37.5 MMSF 4 x 8 ft	75 MMSF 4 x 16 ft	112.5 MMSF 4 x 24 ft	150 MMSF 8 x 24 ft
	------------------------$/MSF, 1/2-inch------------------------			
ngview, Washington				
100% flakes	214.35	--	--	--
40% flakes/ 60% chips	229.05	185.99	172.32	169.96
40% logs/ 60% chips	251.78	201.11	184.76	180.04
dford, Oregon				
100% flakes	211.92	--	--	--
40% flakes/ 60% chips	226.42	183.50	170.00	167.64
40% logs/ 60% chips	250.67	200.25	183.93	179.20
Grande, Oregon				
100% flakes	216.19	--	--	--
40% flakes/ 60% chips	231.29	187.06	173.13	170.77
40% logs/ 60% chips	261.38	209.30	192.57	187.76

urce: Derived from estimating equations developed at U.S. Forest Products
Laboratory, Madison, Wisconsin.

all pieces in the woods could reduce od costs somewhat, but costs for small eces would still be higher than for rger pieces.

Costs of Manufacturing
Structural Flakeboard

Costs of manufacturing were estimated r three types of wood raw material sup- y (flakes, flakes/chips, and logs/chips), ur press sizes, and four plant sizes nging from 37.5 MMSF to 150 MMSF nual production, 1/2-inch thickness.

Actual production could be in 3/8-, 2-,5/8-inch, or other thickness, but l costs are shown in this report on a 2-inch basis. The cost calculations clude a 15-percent rate of return on vestment, using a discounted cash flow alysis developed at the U.S. Forest oducts Laboratory, Madison, Wisconsin.

Resulting costs of production, in- uding wood costs, range from $169.96/MSF, 2-inch basis (Longview, 150 MMSF per ar, 40 percent flakes and 60 percent chips) $261.38/MSF (La Grande, 37.5 MMSF per ar, 40 percent logs and 60 percent

chips) (Table 4). These are calculated using $33 per oven dry ton cost of pur- chased chips ("Maxi-chips" 2 to 3 inches in length), and delivered logs costs of $23, $26, and $35 per oven dry ton in Longview, Medford, and La Grande, res- pectively.

Estimating equations were developed to permit calculating production costs for any wood cost (Table 5). These may be used to calculate the effect on total production costs of any increase or de- crease in wood cost or to calculate the amount of change in wood cost necessary to achieve a given target for total production cost.

Likely Market Value of
Structural Flakeboard

The principal potential market for structural flakeboard is for 1/2-inch sheathing panels corresponding to 1/2-inch CDX softwood plywood. In order to compete with softwood plywood, it was assumed that structural flakeboard would have to sell at 10 percent or more under the price of softwood plywood.

Los Angeles was chosen as an assumed primary market for structural flakeboard

Site and Wood Supply	Press Size							
	4 x 8 ft		4 x 16 ft		4 x 24 ft		8 x 24 ft	
	a	b	a	b	a	b	a	b
	\$/MSF, 1/2-inch basis							
Longview, Washington								
100% flakes	172.90	1.256	--	--	--	--	--	--
40% flakes/ 60% chips	187.60	1.256	144.90	1.245	131.40	1.240	129.80	1.217
40% logs/ 60% chips	213.30	1.327	163.00	1.314	146.80	1.309	142.80	1.284
Medford, Oregon								
100% flakes	171.40	1.228	--	--	--	--	--	--
40% flakes/ 60% chips	185.90	1.228	143.40	1.215	130.00	1.212	128.40	1.189
40% logs/ 60% chips	211.50	1.297	161.50	1.283	145.30	1.279	141.30	1.255
La Grande, Oregon								
100% flakes	175.50	1.233	--	--	--	--	--	--
40% flakes/ 60% chips	190.60	1.233	146.80	1.220	133.00	1.216	131.40	1.193
40% logs/ 60% chips	217.30	1.304	165.70	1.290	149.10	1.286	145.10	1.262

[1] Production cost (\$/MSF) = a + bX, where a is production cost excluding wood cost, and b is coefficient of wood cost per ovendry ton (X). Production costs include taxes, profit (15% IRR), and selling expenses (5, 3, and 2%).

from Pacific Northwest plants. In 1976, the wholesale delivered price of 1/2-inch CDX plywood in Los Angeles was about \$185/ MSF. Ninety percent of this would be \$166.50. Subtracting representative freight charges from Longview, Medford, and LaGrande gave \$142.17, \$147.47, and \$142.73/MSF, respectively, as the target f.o.b. mill price structural flakeboard would have to meet in order to be competitive with soft-wood plywood (Table 6).

Other primary markets than Los Angeles could have been chosen, such as Seattle, Salt Lake City, San Francisco, or Omaha; however, subtraction of freight costs from these markets should give about the same target f.o.b. mill prices as to Los Angeles.

Conclusions

Comparison of production costs with target f.o.b. mill prices indicates that at 1976 costs and prices structural flakeboard would not be competitive with 1/2-inch CDX softwood plywood, under the requirement that structural flakeboard undersell softwood plywood by 10 percent and earn a 15 percent rate of return on investment.

Using the coefficients shown in Table 5, we find that target f.o.b. mill prices could, however, be met in the larger size plants if wood costs were about \$10 to \$12 per ovendry ton in the Longview and La Grande areas, and \$15 to \$17 per ovendry ton in the Medford area. Such low costs for wood supply seem unlikely. Alternatively, a price rise of \$25 to \$30/MSF for 1/2-inch CDX softwood plywood, without any increase in costs for structural flake-board, would put flakeboard within the competitive range in western markets.

Remodeling older particleboard plants might offer a chance to save on initial investment cost, but this would be offset at least in part by higher operating costs.

Analysis of data reported from Eastern and Southern United States potential sites for production of structural flakeboard indicates that those sites are in a much more favorable position to compete with softwood plywood in their market areas. This is due to 1) the higher market price of plywood in eastern markets, 2) the lower freight costs for structural

Table 6. – CALCULATION OF TARGET F.O.B. MILL PRICES FOR
1/2-INCH STRUCTURAL FLAKEBOARD TO BE COMPETITIVE WITH
CDX 1/2-INCH SOFTWOOD PLYWOOD, 1976

Plant Location	CDX Softwood Plywood Los Angeles market price	Structural Flakeboard Competitive price	Freight cost	Target f.o.b. mill price
	----------------------------$/MSF, 1/2-inch basis--------------------			
ngview, Washington	185	166.50	24.33	142.17
dford, Oregon	185	166.50	19.03	147.47
Grande, Oregon	185	166.50	23.77	142.73

akeboard from eastern and southern
urces, and 3) lower costs for labor and
w materials.

In conclusion, it appears that struc-
ral flakeboard from the Pacific North-
st, as of 1976, could not compete with
akeboard produced closer to eastern and
uthern markets, nor could it compete
fectively with CD exterior grade soft-
od plywood in western markets without
substantial price rise for the com-
ting plywood.

References

Heebink, Bruce G. 1974. Particle-
ards from lodgepole pine forest residue.
DA Forest Serv. Res. Pap FPL 221.
rest Prod. Lab., Madison, Wis.

Howard, James O. 1973. Logging resi-
e in Washington, Oregon, and California--
lume and characteristics. USDA Forest
rv. Resour. Bull. PNW-44. Pacific
rthwest For. and Range Exp. Stn.,
rtland, Ore.

Lehmann, W. F. 1977. A perpetual
pply of construction sheathing panels?
ywood & Panel Magazine 17(8):63-65.

Lehmann, W.F., and R.L. Geimer. 1974.
operties of structural particleboards
om Douglas-fir forest residues. For.
od. J. 24(10):17-25.

Maloney, Thomas M., John W. Talbott,
al. 1973. Composition board from
anding dead white pine and dead lodge-
le pine. In Proc. 10th Washington State
iv. Particleboard Symp., Pullman, Wash.

Ramaker, Terry J., and W. F. Lehmann.
76. High-performance structural flake-
ards from Douglas-fir and lodgepole pine
rest residues. USDA Forest Serv. Res.
p. FPL 286, Forest Prod. Lab., Madison,
s.

7. U.S. Department of Agriculture, Forest
Service. 19 . Region 6 appraisal hand-
book. USDA For. Serv. Region 6, Pacific
Northwest Region, Portland, Ore.

8. Withycombe, Richard. 1975. The out-
look for particleboard manufacture in the
northern Rocky Mountain region. USDA
Forest Serv. GTR INT-21. Intermountain
For. and Range Exp. Stn., Ogden, Utah.

PRODUCTION OPPORTUNITIES IN NORTHERN CALIFORNIA

George B. Harpole
Economist
USDA Forest Service
Madison, Wisconsin

Abstract

Logging-type residues available
within 200 miles of Arcata, Calif.
average about 100,000 ovendry tons per
year. Another 518,000 tons of mill
residues are available annually from the
same area. Wood residue volumes appear
sufficient to support wood requirements
for at least one large structural flake-
board plant. Estimates of wood supply
cost (1976 basis) range from about $26
to $35 per ovendry ton, depending upon
form and transportation distance.
Economic analysis indicates that an ef-
ficiently sized structural flakeboard
plant should be able to support wood
costs for logs and chips ranging up to
$38 per ovendry ton or higher depending
upon product market value.

Techniques for the production of
structural flakeboard products from
hardwood and softwood logging residue-
type materials have been determined.
Additionally, the costs of manufacturing
structural flakeboard products from
logging residues have been estimated
for four different sizes of facilities
for northern California sites. Facility
operating costs, excluding wood costs,
have also been estimated for an Arcata,
Calif. site. The objective of this
paper is to present estimates of
available annual volumes and harvesting
costs of logging residues, to provide
estimates of structural flakeboard
production costs which include wood
costs, and to assess the economic
feasibility of manufacturing structural
flakeboard from a northern California
site.

California Forest Resources

Development of the forest industry
in California began with the discovery
of gold in 1848 (4). Early logging and
milling activities were confined to the
more accessible coastal areas and the
mining centers in the central Sierra
Nevada. Following the initial period of
mining activity, population increases
and resultant growth of coastal and in-
terior cities resulted in a continued
growth of wood products manufacture--
primarily in the regions north of the
San Francisco latitude. The northern
regions of California account for about
77 percent of the available commercial
forest area in California--about 13
million acres.

The long history and localized nature
of the forest industry in California have
resulted in a forest resource of complex
structure. Large areas of mature second-
growth timber are found concentrated in
the more accessible North Coastal and
Central Sierra areas of the State, pri-
marily on private land. But, there are
still large areas of National Forest lands
stocked with old-growth sawtimber. Also,
the forests of northern California are
highly differentiated due to the climatic
influence of the coastal mountain ranges;
the result is the heavily stocked redwood-
Douglas-fir stands of "west side" coastal
influence and the more sparsely stocked
pine-fir stands of the "east side" inland
influence (Fig. 1).

Over the past decade, log production
from California forests has ranged from 5
to 6 billion board feet (Scribner log scale).
About 40 percent of this production is cur-
rently from the west side and 47 percent
from the east side (2,4). Between 40 and
50 percent of total log production is
obtained from National Forest lands.

Availability of Forest Residue

Per acre volumes of available log-
ging residues vary sharply because of
differences between the pine-fir stands
of the east side and the redwood-Douglas-
fir stands of the west side, different
harvesting systems used, and cull-log
demand. One study indicated that west
side areas average about 2,755 cubic feet
of logging-type residues per acre (net
volume). The east side averages only
400 cubic feet per acre (3). In view of
this information, analysis of the
feasibility of manufacturing structural
flakeboard was confined to consideration
of a west side site (Arcata, Calif.) that
could efficiently draw upon major concen-
trations of logging residues.

Cruise defect of west side National
Forest timber averages around 30 percent
of gross stand volume, or about 35,000
board feet (Scribner scale) per acre (5).
Correspondingly, scaling defect of log
harvests averages about 25 percent of
gross scale volume, reflecting a sub-
stantial volume of chippable and peelable
cull log removal. Slash volume left in
the woods from over 4,150 acres of yearly
regeneration harvest from west side
National Forest lands amounts to about
1,460 cubic feet per acre.

About 55 percent of the total logging
idue volume is obtainable without new
d construction, which could supply about
million cubic feet or about 50,000
ndry tons of logging residues per year
and 37 pcf dry weight green volume
is, respectively for softwoods and
dwoods) from National Forest harvests
ble 1). About 30 percent of this
ume might be of mixed hardwood species.

An equal or greater volume of log
duction is obtained from State and
vate forest lands, but in many areas
m second-growth stands yielding less
n old-growth stand averages of logging
idues. A reasonable estimate of total
ging residue volume available to an
ata manufacturing site might be about
ce the volume available from the
ional Forest, or about 100,000 oven-
tons per year.

Also, partly due to chippable and
lable cull log harvest, 2.8 million
ndry tons of softwood manufacturing
idues were generated in 1973 (2).
ut 1.8 million tons of these residues
e reported to have been used as fuel
for the production of other wood and
d fiber products. About 900,000 tons
these residues were reported to have
n unused. In 1974, a survey of 70
ls in Humboldt County indicated the
ilability of about 518,000 tons of
sed softwood sawmill residues within
istance of 200 miles from the Arcata
a (Table 2). These are surplus
idue volumes either being burned or
ied in landfills. Although these
e the dregs of primary manufacturing
cesses, some volume of these mill
idues can be expected to be in the
m of sawmill edgings and rims (up to
percent) that could be used for the
duction of structural flakeboard (1).

Wood Requirements

Structural flakeboard cannot be
duced from the customary mixtures of
er shavings and sawdust used for
ticleboard manufacture. At least 30
cent of the structural flakeboard
nish must be of high quality flake,
n as produced from roundwood using
isk flaker or shaping lathe headrig
produce the high-strength faces re-
red for predictable structural per-
mance. Core furnish, up to 70 per-
t, however, may be prepared by the
king of maxichips (2 to 3 inches long)
ng a ring flaker. Consequently,
ndwood and other forms of unchipped
idues are needed to supply at least
percent of the wood raw material for
uctural flakeboard manufacture.

Four different sizes of structural
keboard facilities were analyzed. In-
tment costs for the largest facilities
e about three times those for the
llest facilities considered, and wood

raw material requirements ranged from
about 40,500 to 156,700 ovendry tons per
year (Table 3). Because economies of
scale are substantial, and wood raw
material supplies become of paramount im-
portance for commercial feasibility, care-
ful consideration needs to be given to
choosing the scale of a prospective new
facility.

Costs of Harvesting Logging Residues

Costs of mill residues and logging
residues differ because slabs, edgings,
and veneer cores reflect the joint costs
of primary processing. Consequently,
the costs of mill residues to a buyer
of wood raw materials for structural
flakeboard production will probably re-
flect the going market price for pulp
chips. Over the past 5 years pulp chip
prices in the Arcata-Eureka area have
reportedly ranged from $20 to $60 per
bone dry unit (2,400 lb bone dry wood),
or about $17 to $50 per ovendry ton.
The per-ton costs of harvesting and trans-
porting logging residues are estimated
to range from $26 to $35 per ovendry ton
(Table 4), costs which probably also
influence the purchase-or-harvest deci-
sions of pulp chip users.

Production Costs of
Structural Flakeboard

Estimated production costs for struc-
tural flakeboard at an Arcata, Calif.
site have been estimated to range from
$109 to $191/MSF (1/2-inch basis), ex-
cluding wood costs. Production costs vary
with the size of the facility, and to some
extent with the amount of pre-processing
required for utilizing roundwood. That
is, processing costs for utilizing round-
wood increase structural flakeboard pro-
duction costs from $10 to $37/MSF, 1/2 inch).
over costs when utilizing chips or flakes.
The full costs of producing structural
flakeboard, including wood costs, can be
estimated by referring to Figures 2
through 5.

Assuming an average wood cost of $33
per ovendry ton, the full cost of produc-
ing structural flakeboard, including wood,
is estimated to range from $149 to $233/
MSF, 1/2 inch, when utilizing softwood.
Due to the greater weight of hardwoods,
chemical and energy costs increase on a
per cubic foot basis. For this reason,
the utilization of hardwoods would in-
crease production costs up to about 4 per-
cent. Structural flakeboard products
would have to be sold at an average f.o.b.
mill price (1976 basis) of from $149 to
$233/MSF, 1/2 inch, to support profitable
production if wood costs averaged $33
per ovendry ton (Figures 2 through 5).

Table 1.--ESTIMATED ANNUAL VOLUMES OF LOGGING RESIDUES AVAILABLE
WITHIN A 200-MILE RADIUS OF ARCATA, CALIF.[1]

Logging Residue	Softwoods (28.1 pct, OD, green vol.)	Hardwoods (37.0 pcf, OD, green vol.)	Total
	----------------------Thousand ODT----------------------		
Gross[2]	64.6	27.8	92.4
Net[3]	53.4	22.2	75.6
Net usable[4]	49.2	20.4	69.6
Net available [5]	35.1	14.8	49.9
Net available barkable[6]	35.1	13.9	48.1
Net available nonbarkable[7]	0	1.9	1.9

[1]Correspondence. May 1974. USDA Forest Service, Region 5. San Francisco, Calif.

[2]Cubic volume of residue materials over minimum diameter of 4 in. and at least 4 ft in length.

[3]That portion of residue material capable of producing sound pulp chips with a 10% minimum recovery, not including rotten, shattered, or missing parts.

[4]Net logging residue minus limb wood, splinters, and slabs over the minimum dimensions.

[5]Logging residue within 60 ft or less of an existing landing.

[6]Capable of being barked by a mechanical barker.

[7]Nonbarkable=(net available volume) — (barkable volume).

Table 2.--ANNUAL VOLUME OF MILL RESIDUES FROM 70 OPERATING SAWMILLS
WITHIN A 200-MILE RADIUS OF ARCATA, CALIF.[1]

Distance from Arcata	Mill Residue Volume
Miles	ODT/yr
0-50	190,752
50-100	172,600
100-200	154,600
Total	517,925

[1]Correspondence. May 1974. USDA Forest Service, Region 5. San Francisco, Calif.

Annual Output Capacity	Wood Raw Material Requirements
MMSF, 1/2-inch basis	Thousand ODT
37.5	40.5
75	80.1
112.5	119.8
150	156.7

Table 4.--ESTIMATED COST OF LOGGING RESIDUES AT ARCATA, CALIF.

Type of Cost	Cull Logs	Chips or Flakes
	----------------$/ODT-----------------	
Overhead expense	2.25	2.25
Road construction	NC	NC
Road maintenance	1.00	1.00
Fall and buck	3.50	.50
Yard	11.00	15.00
Debark, chip and/or flake	NC	7.00
Load	2.50	1.00
Total harvest cost	20.25	26.75
Stumpage cost	0.50	0.50
Transportation:		
50-100 miles	5.00	5.00
100-200 miles	7.50	7.50
Total costs:		
50-100 miles	25.75	32.25
100-200 miles	28.25	34.75

no charge.

Likely Market Value
of Structural Flakeboard

Although structural flakeboard prod-
s might be used as an underlayment grade
CDX sheathing and possibly for specialty
s such as for siding and decorative
el use, the primary opportunity would
bably be in commodity grades of struc-
al sheathing. Of these products, 1/2-
h-thick plywood, CDX, is the most pre-
inant product in use. If structural
keboard products were to compete in the
modity sheathing markets, they would
bably have to be sold at or below the
vailing market costs for comparable
wood sheathing.

An estimate of the maximum average
ket value structural flakeboard might
e attained during 1976, f.o.b. Arcata,
based on the average market price of
, 1/2-inch plywood f.o.b. Los Angeles,
s the higher freight cost of

structural flakeboard. The average market
price for CDX, 1/2-inch plywood f.o.b.
Los Angeles was about $185/MSF, 1/2-inch,
during 1976. Freight costs for 1/2-inch-
thick structural flakeboard weighing
1,962 pounds per thousand square feet,
1/2-inch thick, would be about $15.50 (via
rail, $.79/CST), indicating an f.o.b.
Arcata mill value of about $169.50/MSF,
1/2-inch (subject to trade discounts of
5, 3, and 2 percent).

Assessment of Commercial Feasibility

Assessment of commercial feasibility
can be made by matching expected production
costs of structural flakeboard manufacture
against likely f.o.b. mill value of product
output (Fig. 2). For example, the facility
producing 112.5 MMSF material per year from
flakes and chips, including wood costs
ranging from $30 to $33 per ovendry ton,
indicate production costs ranging from
$153.50 to $157.25--substantially less

than the estimate of f.o.b. mill market value. Conversely, an f.o.b. mill value of $169.50/MSF could be expected to support wood costs up to $43 per ovendry ton (($169.50 - $116)/1.25).

Using the same method of analysis, commercial feasibility would be indicated as a possibility for all but the smallest of the facilities considered (37.5 MMSF per year).

Summary and Conclusions

The long history and localized nature of the California forest industry have resulted in a forest resource of complex structure. Also, in the northern California regions which account for about 87 percent of total log production in the State, forests are highly differentiated between the redwood-Douglas-fir stands of west side coastal influence and the pine-fir stands of east side inland influence. Due to differences between the west side and east side forests, different harvesting systems used, and cull-log demand, per acre volumes of available logging residues vary sharply. Because the per acre volumes of logging residues in the west side forests are about six times the volume of those in the east side forest, analysis of the feasibility of manufacturing structural flakeboard was confined to consideration of a west side site (Arcata, Calif.) that could efficiently draw upon major concentrations of logging residues.

It is estimated that about 100,000 ovendry tons of logging residues should be available to an Arcata site within a distance of 200 miles. About 30 percent of this volume would probably be of mixed hardwood species. Additionally, between 500,000 and 900,000 ovendry tons of unused softwood mill residues are generated annually within a 200-mile radius of Arcata. At least 30 percent of the structural flakeboard furnish must be of high-quality flake, such as produced from roundwood using a disk flaker or shaping lathe headrig to produce the high-strength faces required for predictable structural performance. Logging and mill residue supplies appear sufficient to supply the wood raw material requirements for at least a medium-sized structural flakeboard facility.

Estimates of wood supply costs indicate that the per-ton costs (ovendry) of harvesting and transporting logging residues to an Arcata site would range from about $26 to $35. Mill residues of suitable quality for structural flakeboard manufacture would probably range from about $17 to $50 per ovendry ton,

depending upon markets for pulp chips.

The full costs of producing structural flakeboard, including wood costs averaging $33 per ovendry ton, are estimated to range from $153 to $242/MSF, 1/2 inch, depending upon facility size and amount of roundwood preprocessing required. The average f.o.b. Arcata market value for structural flakeboard products, during 1976, was estimated to be up to $169/MSF, 1/2 inch, and to indicate economic feasibility for all but the smallest facility considered.

References

1. Grantham, John B. 1974. Status of timber utilization on the Pacific Coast. USDA For. Ser. Gen. Tech. Rep. PNW-29. Pacific Northwest Forest Exp. Stn., Portland, Oreg.

2. Howard, James O. 1974. California forest industry wood consumption and characteristics, 1972. USDA For. Ser. Res. Bul. PNW-52. Pacific Northwest Forest Exp. Stn., Portland, Oreg.

3. Howard, James O. 1973. Logging residue volume and characteristics. USDA For. Ser. Res. Bul. PNW-44. Pacific Northwest Forest Exp. Stn., Portland, Oreg.

4. Oswald, Daniel D. 1970. California's Forest Industries--prospects for the future. USDA For. Ser. Resource Bul. PNW-35. Pacific Northwest Forest Exp. Stn., Portland, Oreg.

Figure 1.- Coastal west-side and inland east
side regions of northern California
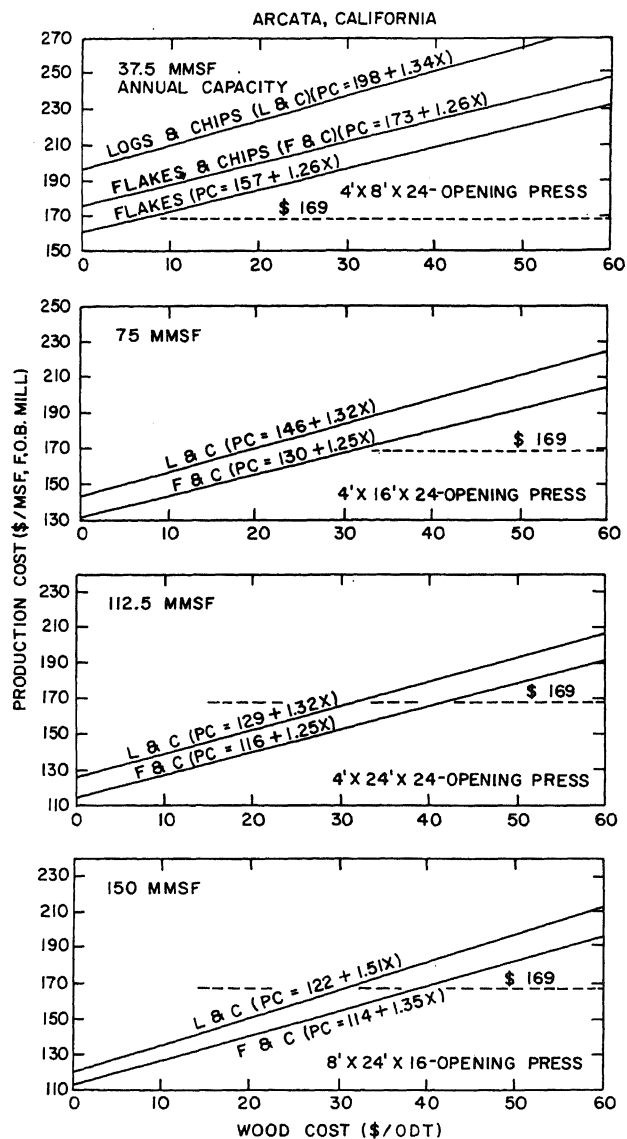
Figure 2.--Production cost (PC) vs wood cost (WC = coeff · X), including taxes, profit (15% IRR), and selling expense (5, 3, and 2%) for manufacture of 1/2-inch structural flakeboard, 1976 basis.

APPENDIX A.--FACILITY EQUIPMENT REQUIREMENTS AND COST ESTIMATES

Table 1A.--DESIGN FLOW RATE FOR LATHE FLAKE UNLOADING & STORAGE

| | Plant Capacity (MMSF 1/2" per annum) | | | |
	37.5	75	112.5	150
	Section Type			
	WF1	WF1a	WF1	WF1	WF1
Percent of total plant flow	40%	100%	40%	40%	40%
O.D. lb/hour	5,000	12,500	10,000	15,000	20,000

Table 1B.--EQUIPMENT COST DETAILS FOR LATHE FLAKE UNLOADING & STORAGE[1],[2]

		Plant Capacity (MMSF 1/2" per annum)			
		37.5		75	112.5	150
		Section Type				
		WF1	WF1a	WF1	WF1	WF1
Total plant flow [3]	O.D. lb/hr		11,250	22,500	34,000	45,000
Average flake flow [3]	O.D. lb/hr	4,500	11,250	9,000	13,600	18,000
Average design flow	O.D. lb/hr	5,000	12,500	10,000	15,000	20,000
Equipment						
Lathe flake reclaim hopper (truck dump)		$25,000	$75,000	$75,000	$75,000	$75,000
Lathe flake silo infeed conveyor		25,000	30,000	30,000	35,000	40,000
Lathe flake silo & distribution conveyor		70,000	120,000	110,000	130,000	150,000
Lathe flake silo outfeed conveyor		15,000	20,000	15,000	20,000	25,000
Conveyor to metering bin		20,000	30,000	20,000	30,000	35,000
Metering bin(s)		20,000	20,000	20,000	35,000	40,000
Magnets		7,000	10,000	7,000	10,000	10,000
Support steel, platforms & walkways		5,000	10,000	5,000	5,000	10,000
Mobile equipment allowance			60,000			
Total Equipment Costs		$187,000	$375,000	$282,000	$340,000	$385,000
Connected HP		120	160	160	170	200

[1] Data from USDA, Forest Products Laboratory, Madison, Wisconsin.
[2] Assumption: Lathe flakes delivered by blower or truck.
[3] Average flake flow is 40% except for Section Type WF1a, for which average flake flow is 100%.

203

Table 1C.--COST SUMMARY FOR LATHE FLAKE UNLOADING & STORAGE FOR 37.5-MMSF CAPACITY PLANT[1]

	Raw Material			
	40% of Plant Capacity (Type WF1)		100% of Plant Capacity (Type WF1a)	
	Materials	Labor	Materials	Labor
Mechanical equipment[2]	$ 187,000		$ 375,000	
Air pollution abatement (filters)	15,000		15,000	
Electrical equipment (PDC's, MCC's, panels & miscellaneous motors)	10,000		12,000	
Installation:				
Mechanical 1,000 hr	5,000	$ 29,000		
1,500 hr			5,000	$ 43,000
Electrical 1,000 hr	10,000	29,000	10,000	29,000
Piping 100 hr	1,000	3,000	1,000	3,000
Concrete machinery				
bases, pads & pits 50 yd @ $ 80	4,000			
@ $100		5,000		
80 yd @ $ 80			6,000	
@ $100				8,000
Totals	$ 232,000	$ 66,000	$ 424,000	$ 83,000
Total Installed Costs (excluding bldgs)	$ 298,000		$ 507,000	
Total Connected HP	120		160	

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.
2/ See Table 1B.

Table 1D.--COST SUMMARY FOR LATHE UNLOADING & STORAGE FOR 75- AND 112.5-MMSF-CAPACITY PLANT[1],[2]

	Plant Capacity (MMSF 1/2" per annum)			
	75		112.5	
	Materials	Labor	Materials	Labor
Mechanical equipment[3]	$ 282,000		$ 340,000	
Air pollution abatement (filters)	15,000		18,000	
Electrical equipment (PDC's, MCC's, panels & miscellaneous motors)	13,000		15,000	
Installation:				
Mechanical 1,500 hr	5,000	$ 43,000	5,000	$ 43,000
Electrical 1,200 hr	12,000	35,000	12,000	35,000
Piping 100 hr	1,000	3,000	1,000	3,000
Concrete machinery				
bases, pads, & pits 80 yd @ $ 80	6,000			
@ $100		8,000		
100 yd @ $ 80			8,000	
@ $100				10,000
Totals	$ 334,000	$ 89,000	$ 399,000	$ 91,000
Total Installed Cost (excluding bldgs)	$ 423,000		$ 490,000	
Total Connected HP	160		170	

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.
2/ Section capacity 40%, Type WF1.
3/ See Table 1B.

Table 1E.--COST SUMMARY FOR LATHE FLAKE UNLOADING & STORAGE
FOR 150-CAPACITY PLANT[1],[2]

	Materials	Labor
Mechanical equipment[3]	$ 385,000	
Air pollution abatement (filters)	20,000	
Electrical equipment (PDC's, MCC's, panels & miscellaneous motors)	20,000	
Installation:		
Mechanical 1,500 hr	5,000	$ 43,000
Electrical 1,200 hr	14,000	35,000
Piping 100 hr	1,000	3,000
Concrete machinery		
bases, pads, & pits 120 yd @ $ 80	10,000	
@ $100		12,000
Totals	$ 451,000	$ 93,000
Total Installed Costs (excluding bldgs)	$ 544,000	
Total Connected HP	200	

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.
2/ Section capacity 40%, Type WF1.
3/ See Table 1B.

Table 2A.--DESIGN FLOW RATE FOR TREE-LENGTH LOG HANDLING, BARKING & FLAKING

	Plant Capacity (MMSF 1/2" per annum)			
	37.5	75	112.5	150
Design flow rate (O.D. lb/hour)[1] Actual capacity of section, determined by flaker capacity, limited by other component equipment (O.D. lb/hour	5,000 20,000	10,000 25,000	15,000 30,000	20,000 30,000

1/ Section capacity 40% of total plant flow, Type WF2.

Table 2B.--EQUIPMENT COST DETAILS FOR TREE-LENGTH LOG HANDLING, STORAGE & FLAKING SECTION[1]

	Plant Capacity (MMSF 1/2" per annum)[2]		
	75	112.5	150
Total average plant flow O.D. lb/hr	22,500	34,000	45,000
Average material flow O.D. lb/hr flaking section (40% of total) (Type WF2)	9,000	13,600	18,000
Average design flow O.D. lb/hr flaking section	10,000	15,000	20,000
Equipment			
Pre-thaw pond or deck	$ 30,000	$ 35,000	$ 40,000
Inclined feed conveyors	15,000	15,000	15,000
Pumps, piping or drives	10,000	10,000	10,000
Log conveyor & holddowns	25,000	30,000	40,000
Primary slasher, conveyor & saw (8')	150,000	150,000	150,000
Reject log conveyor	15,000	15,000	15,000
Log chain conveyor	60,000	60,000	70,000
Chipper or hog	30,000	30,000	40,000
Chipper conveyor	15,000	15,000	20,000
Barker infeed conveyor	15,000	15,000	15,000
Barker	75,000	75,000	75,000
Barker outfeed & holddowns	15,000	15,000	15,000
Barker hog conveyor	25,000	30,000	30,000
Barker waste conveyor	20,000	20,000	25,000
Barker hog	20,000	25,000	30,000
Debarked log thaw pond, piping & pumps	20,000	25,000	30,000
Pond outfeed conveyors	15,000	20,000	25,000
Log conveyor	10,000	15,000	15,000
Secondary slasher (4')	15,000	15,000	20,000
Flaker feed sections (3)	30,000	40,000	40,000
Drum flaker (4'-0") with drive	195,000	195,000	195,000
Flaker conveyor to bin	40,000	40,000	40,000
Green bark bin	60,000	60,000	70,000
Outfeed conveyor	15,000	15,000	20,000
Wet flake bin & distribution conveyor	100,000	120,000	140,000
Outfeed conveyor	15,000	20,000	25,000
Conveyor to dryer metering bin	20,000	25,000	30,000
Dryer metering bin	20,000	35,000	40,000
Walkways and supports	25,000	30,000	35,000
Mobile equipment	175,000	175,000	225,000
Shop equipment allowance	15,000	15,000	20,000
Total Equipment Costs	$ 1,290,000	$ 1,385,000	$ 1,560,000
Total Connected HP	1,300	1,400	1,500

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.
2/ Section not estimated in detail for 37.5-MMSF plant capacity. Total equipment cost $190,000 less than 75-MMSF-capacity section.

Table 2C.—SECTION COST SUMMARY FOR TREE-LENGTH LOG HANDLING, BARKING, & FLAKING[1/],[2/]

| | Plant Capacity (MMSF 1/2" per annum) | | | |
	37.5		75	
	Materials	Labor	Materials	Labor
Mechanical equipment[3/]	$ 1,100,000[4/]		$ 1,290,000	
Air pollution abatement (filters)	10,000		10,000	
Electrical equipment (PDC's, MCC's, panels & miscellaneous motors)	90,000		90,000	
Installation:				
Mechanical 5,000 hr	10,000	$ 145,000	10,000	$ 145,000
Electrical 4,000 hr	30,000	116,000	30,000	116,000
Piping 2,500 hr	20,000	72,000	20,000	72,000
Concrete machinery 150 yd @ $ 80	12,000		12,000	
bases, pads & pits @ $100		15,000		15,000
Soaking pond 200 yd @ $ 80	16,000			
concrete @ $100		20,000		
250 yd @ $ 80			20,000	
@ $100				25,000
Total	$ 1,288,000	$ 368,000	$ 1,482,000	$ 373,000
Total Installed Cost	$ 1,656,000		$ 1,855,000	
Total Connected HP	1,260		1,300	

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.
2/ Section capacity 40%, Type WF2.
3/ See Table 2B.
4/ See footnote 2 in Table 2B.

Table 2D.—SECTION COST SUMMARY FOR TREE-LENGTH LOG HANDLING, BARKING, & FLAKING[1/],[2/]

| | Plant Capacity (MMSF 1/2" per annum) | | | |
	112.5		150	
	Materials	Labor	Materials	Labor
Mechanical equipment[3/]	$ 1,385,000		$ 1,560,000	
Air pollution abatement (filters)	10,000		10,000	
Electrical equipment (PDC's, MCC's, panels & miscellaneous motors)	100,000		110,000	
Installation:				
Mechanical 5,200 hr	10,000	$ 150,000		
5,500 hr			10,000	$ 160,000
Electrical 4,500 hr	33,000	130,000	35,000	130,000
Piping 2,800 hr	25,000	82,000		
3,200 hr			28,000	93,000
Concrete machinery 180 yd @ $ 80	15,000		15,000	
bases, pads & pits @ $100		18,000		18,000
Soaking pond 350 yd @ $ 80	28,000			
concrete @ $100		35,000		
400 yd @ $ 80			32,000	
@ $100				40,000
Total	$ 1,608,000	$ 415,000	$ 1,800,000	$ 441,000
Total Installed Cost (excluding bldgs)	$ 2,023,000		$ 2,241,000	
Total Connected HP	1,400		1,500	

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.
2/ Section capacity 40%, Type WF2.
3/ See Table 2B.

Table 3A.--DESIGN FLOW RATE FOR CHIP HANDLING, STORAGE, & FLAKING

	Plant Capacity (MMSF 1/2" per annum)			
	37.5	75	112.5	150
O. D. lb/hour	7,500	15,000	22,500	30,000

1/ Section capacity 60% of total plant flow, Type WF3.

Table 3B.--EQUIPMENT COST DETAILS FOR CHIP HANDLING, STORAGE, & FLAKING SECTION[1]

		Plant Capacity (MMSF 1/2" per annum)			
		37.5	75	112.5	150
Total average plant flow	O.D. lb/hr	11,250	22,500	34,000	45,000
Average material flow chip section (60% of total) (Type WF3)	O.D. lb/hr	6,800	13,500	20,500	27,000
Average design flow chip section	O.D. lb/hr	7,500	15,000	22,500	30,000
Equipment					
Truck dump		$ 75,000	$ 75,000	$ 75,000	$ 75,000
Inclined belt conveyor		20,000	25,000	25,000	30,000
Conveyor to stacker		15,000	15,000	15,000	20,000
Radial stacker		35,000	35,000	35,000	30,000
Reclaim hopper		20,000	25,000	30,000	30,000
Conveyor to storage bin		20,000	20,000	25,000	30,000
Chip storage bin with distribution conveyor		60,000	80,000	80,000	90,000
Bin outfeed conveyor		15,000	15,000	20,000	25,000
Conveyor to chip screen		10,000	10,000	12,000	15,000
Chip screen		15,000	15,000	20,000	25,000
Chip conveyor to flaker bins		15,000	25,000	30,000	40,000
Fines blower to boiler		15,000	20,000	20,000	20,000
Metering bins		10,000	20,000	30,000	40,000
Infeed screws		5,000	10,000	15,000	25,000
Ring flakers		110,000 (1)	220,000 (2)	340,000 (3)	460,000 (4)
Vibrating feeders		6,000	12,000	18,000	25,000
Pneumatic conveyors to dryers		20,000	40,000	60,000	80,000
Magnets and chutes		6,000	12,000	20,000	20,000
Support steel, platforms, walkways		10,000	15,000	25,000	30,000
Mobile equipment		100,000	150,000	150,000	150,000
Shop equipment		10,000	15,000	20,000	25,000
Total Equipment Costs		$ 592,000	$ 854,000	$ 1,065,000	$ 1,285,000
Total Connected HP		725	1,300	1,900	2,400

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.

Table 3C.--SECTION COST SUMMARY FOR CHIP HANDLING & FLAKING[1,2]

| | | Plant Capacity (MMSF 1/2" per annum) | | | |
| | | 37.5 | | 75 | |
		Materials	Labor	Materials	Labor
Mechanical equipment[3]		$ 592,000		$ 854,000	
Air pollution abatement (filters)		25,000		25,000	
Electrical equipment (PDC's, MCC's, panels & miscellaneous motors		60,000		90,000	
Installation:					
Mechanical	2,500 hr	3,000	73,000		
	3,000 hr			5,000	87,000
Electrical	2,000 hr	10,000	58,000		
	3,000 hr			28,000	73,000
Piping	300 hr	4,000	6,000		
	500 hr			10,000	14,000
Concrete machinery bases, pads & pits	150 yd @ $ 80	12,000			
	@ $100		15,000		
	200 yd @ 80			16,000	
	@ $100				20,000
Total		$ 706,000	$ 152,000	$1,018,000	$ 194,000
Total Installed Cost (excluding bldgs)		$ 858,000		$ 1,212,000	
Total Connected HP		725		1,300	

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.
2/ Section capacity 60%, Type WF3.
3/ See Table 3B.

Table 3D.--SECTION COST SUMMARY FOR CHIP HANDLING & FLAKING[1,2]

| | | Plant Capacity (MMSF 1/2" per annum) | | | |
| | | 112.5 | | 150 | |
		Materials	Labor	Materials	Labor
Mechanical equipment[3]		$ 1,065,000		$ 1,285,000	
Air pollution abatement (filters)		25,000		30,000	
Electrical equipment (PDC's, MCC's, panels & miscellaneous motors)		120,000		140,000	
Installation:					
Mechanical	3,500 hr		101,000		
	4,000 hr				116,000
Electrical	3,500 hr	32,000	101,000		
	4,000 hr			36,000	116,000
Piping	800 hr	12,000	23,000		
	1,000 hr			14,000	29,000
Concrete machinery bases, pads & pits	250 yd @ $ 80	20,000			
	@ $100		25,000		
	300 yd @ $ 80			24,000	
	@ $100				30,000
Total		$ 1,274,000	$ 250,000	$ 1,529,000	$ 291,000
Total Installed Cost (excluding bldgs)		$ 1,524,000		$ 1,820,000	
Total Connected HP		1,900		2,400	

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.
2/ Section capacity 60%, Type WF3.
3/ See Table 3B.

TABLE 4A.--DRYER LINE FLOW TYPES FOR
VARIOUS PLANT CAPACITIES

Plant Capacity	Dryer Type
MMSF 1/2" per annum	
37.5	Type DB1, Single Dryer Line Flow
75	Type DB2, Double Dryer Line Flow
112.5	" "
150	" "

Table 4B.--EQUIPMENT COST DETAILS FOR DRYING, SCREENING & BLENDING SECTION
FOR 37.5- AND 75-MMSF-CAPACITY PLANT[1,2]

		Plant Capacity (MMSF 1/2" per annum)				
		37.5			75	
		Section Type				
		DB1	DB2		DB2	
Total average plant flow	O.D. lb/hr	11,250	11,250		22,500	
Total design flow	O.D. lb/hr	12,500	12,500		25,000	
Raw material stream		100% Flake	40% Flake;	60% Chip	40% Flake;	60% Chip
Design flow of section	O.D. lb/hr	12,500	5,000	7,500	10,000	15,000
Number of dryers		1	1	1	1	1
Equipment						
Dryer infeed conveyor		$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000
Dryer (wood/gas/oil burners)		300,000	175,000	200,000	250,000	330,000
Fire screw conveyor		5,000	5,000	5,000	5,000	5,000
Screen infeed conveyors		10,000	8,000	8,000	10,000	10,000
Shaker screen		15,000	10,000	10,000	15,000	18,000
Screen outfeed conveyors		5,000	3,000	4,000	5,000	6,000
Conveyors to dry metering bins		12,000	10,000	10,000	12,000	12,000
Dry metering bins with outfeed		80,000	40,000	50,000	60,000	70,000
Weighing conveyors		20,000	10,000	10,000	12,000	15,000
Weigh scales & instrumentation		20,000	10,000	10,000	12,000	12,000
Blenders		40,000	20,000	20,000	30,000	30,000
Blender outfeed conveyor		10,000	5,000	5,000	5,000	7,000
Conveyor to former		30,000	15,000	15,000	20,000	23,000
Resin & wax tanks, pumps, piping & installation		45,000	20,000	25,000	25,000	30,000
Subtotals		$ 602,000	$ 341,000	$ 382,000	$ 471,000	$ 578,000
Combined Total		$ 602,000	$ 723,000		$ 1,049,000	
Walkways, platforms & support steel		30,000	45,000		50,000	
Fines to fuel system		15,000	20,000		25,000	
Fines collecting conveyor		15,000	18,000		20,000	
Fines transfer to fuel bin		20,000	20,000		25,000	
Shop equipment allowance		10,000	10,000		10,000	
Total Equipment Costs		$ 692,000	$ 836,000		$ 1,179,000	
Total Connected HP		450	570		880	

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.
2/ DB1, Single Flow System; DB2, Dual Flow System.

Table 4C.--EQUIPMENT COST DETAILS FOR DRYING, SCREENING, & BLENDING SYSTEM
FOR 112.5- AND 150-MMSF-CAPACITY PLANTS[1],[2]

		Plant Capacity (MMSF 1/2" per annum)			
		112.5		150	
		Section Type			
		DB2		DB2	
Total average plant flow	O.D. lb/hr	34,000		45,000	
Total design flow	O.D. lb/hr	37,500		50,000	
Raw material stream		40% Flakes; 60% Chips		40% Flakes; 60% Chips	
Design flow of section	O.D. lb/hr	15,000	22,500	20,000	30,000
Number of dryers		1	2	2	2
Equipment					
Dryer infeed conveyor		$ 10,000	$ 20,000	$ 20,000	$ 20,000
Dryer (wood/gas/oil burners)		330,000	500,000	500,000	650,000
Fire screw conveyor		5,000	8,000	18,000	10,000
Screen infeed conveyors		10,000	20,000	20,000	20,000
Shaker screen		18,000	30,000	30,000	40,000
Screen outfeed conveyors		6,000	10,000	10,000	12,000
Conveyors to dry metering bins		12,000	15,000	15,000	18,000
Dry metering bins with outfeed		70,000	80,000	80,000	100,000
Weighing conveyors		15,000	18,000	18,000	20,000
Weigh scales & instrumentation		12,000	15,000	15,000	18,000
Blenders		30,000	40,000	40,000	50,000
Blender outfeed conveyor		7,000	10,000	10,000	14,000
Conveyor to former		23,000	28,000	25,000	30,000
Resin & wax tanks, pumps, piping & installation		30,000	35,000	35,000	45,000
Subtotals		$ 578,000	$ 829,000	$836,000	$ 1,047,000
Combined Total		$ 1,407,000		$ 1,883,000	
Walkways, platforms & support steel		65,000		75,000	
Fines to fuel system		25,000		30,000	
Fines collecting conveyor		20,000		25,000	
Fines transfer to fuel bin		30,000		35,000	
Shop equipment allowance		15,000		15,000	
Total Equipment Costs		$ 1,562,000		$ 2,063,000	
Total Connected HP		1,180		1,550	

[1] Data from USDA, Forest Products Laboratory, Madison, Wisconsin
[2] DB2, Dual Flow System.

Table 4D.--SECTION COST SUMMARY FOR DRYING, SCREENING, & BLENDING FOR 37.5-MMSF-CAPACITY PLANT[1]

		Section Type		
		Type DB1		Type DB2
		Raw Material		
		100% Flakes		40% Flakes; 60% Chips
		Materials	Labor	Materials	Labor
Mechanical equipment[2]		$ 692,000		$ 836,000	
Air pollution abatement (filters)		25,000		25,000	
Electrical equipment (PDC's, MCC's, panels & miscellaneous motors)		40,000		54,000	
Installation:					
Mechanical	2,500 hr	5,000	$ 72,000		
	3,000 hr			8,000	$ 87,000
Electrical	2,000 hr	20,000	58,000		
	2,500 hr			25,000	72,000
Piping	1,500	20,000	42,000		
	2,000 hr			25,000	58,000
Concrete machinery	80 yd @ $ 80	6,000			
bases, pads & pits	@ $100		8,000		
	100 yd @ $ 80			8,000	
	@ $100				10,000
Total		$ 808,000	$ 180,000	$ 981,000	$ 227,000
Total Installed Cost (excluding bldgs)		$ 988,000		$ 1,208,000	
Total Connected HP		450		570	

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.
2/ See Table 4B.

Table 4E.--SECTION COST SUMMARY FOR DRYING, SCREENING, & BLENDING
FOR 75- AND 112.5-MMSF-CAPACITY PLANT[1],[2]

		Plant Capacity (MMSF 1/2" per annum)			
		75		112.5	
		Raw Material			
		40% Flakes; 60% Chips		40% Flakes; 60% Chips	
		Materials	Labor	Materials	Labor
Mechanical equipment[3]		$ 1,179,000		$ 1,562,000	
Air pollution abatement (filters)		35,000		45,000	
Electrical equipment (PDC's, MCC's, panels & miscellaneous motors)		70,000		90,000	
Installation:					
Mechanical	4,000 hr	10,000	$ 116,000		
	5,000 hr			15,000	$ 145,000
Electrical	3,000 hr	30,000	87,000		
	4,000 hr			40,000	116,000
Piping	2,500 hr	30,000	72,000		
	3,000 hr			40,000	87,000
Concrete machinery	150 yd @ $ 80	12,000			
bases, pads & pits	@ $100		15,000		
	200 yd @ $ 80			16,000	
	@ $100				20,000
Total		$ 1,366,000	$ 290,000	$ 1,808,000	$ 368,000
Total Installed Cost (excluding bldgs)		$ 1,656,000		$ 2,176,000	
Total Connected HP		880		1,180	

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.
2/ Section Type DB2.
3/ See Table 4B.

Table 4F.--SECTION COST SUMMARY FOR DRYING, SCREENING, &
BLENDING FOR A 150-MMSF-CAPACITY PLANT[1],[2]

| | | Raw Material | |
| | | 40% Flakes; 60% Chips | |
		Materials	Labor
Mechanical equipment[3]		$ 2,063,000	
Air pollution abatement (filters)		60,000	
Electrial equipment (PDC's, MCC's, Panels & miscellaneous motors)		110,000	
Installation:			
Mechanical	6,500 hr	20,000	$ 188,000
Electrical	5,000 hr	50,000	145,000
Piping	4,000 hr	45,000	116,000
Concrete machinery	280 yd @ $ 80	23,000	
bases, pads & pits	@ $100		28,000
Total		$ 2,371,000	$ 477,000
Total Installed Cost (excluding bldgs)		$ 2,848,000	
Total Connected HP		1,550	

1/ Data from USDA, Forest Products Laboratory, Madison,
Wisconsin.
2/ Section Type DB2.
3/ See Table 4B.

213

Table 5A.--PRESS SIZES FOR VARIOUS PLANT CAPACITIES

Plant Capacities	Press Sizes
MMSF 1/2" per annum	
37.5	Continuous Press (Bison-DeMets Type)
	4' x 8' 24 openings (Caul System)
	4' x 16' 12 openings "
75	4' x 16' 24 openings "
112.5	4' x 24' 24 openings "
	8' x 24' 12 openings (Caul System or "Flexoplan")
150	8' x 24' 16 openings " "

Table 5B.--EQUIPMENT COST DETAILS FOR FORMING, PRESSING & BOARD TRIMMING SECTION FOR 37.5- AND 75-MMSF-CAPACITY PLANTS[1]

	Plant Capacity (MMSF 1/2" per annum)			
	37.5			75
	Press Size and Configuration			
	Continuous	4' x 8' 24 opening	4' x 16' 12 opening	4' x 16' 24 opening
Equipment				
Forming machine	Included	$ 300,000	$ 300,000	$ 400,000
Press, loader, unloader, caul system, weigh scale, B & C separator, board cooler, including cauls & electrical system	$ 2,200,000	1,350,000	1,660,000	1,975,000
Clean-up screw		15,000	20,000	20,000
Mat saw pneumatics		15,000	15,000	15,000
Reject hopper with outfeed	Included	15,000	20,000	25,000
Reject conveyor to bin		20,000	20,000	25,000
Reject bin with outfeed		30,000	30,000	50,000
Press exhaust hood & fans	10,000	10,000	15,000	15,000
Press pit clean-up system		8,000	10,000	10,000
Bypass stacker & feeder		20,000	30,000	30,000
Trim saw, including transfers and trim breaker	Included	110,000	160,000	160,000
Saw stacker & outfeed rools		25,000	32,000	32,000
Trim conveyors		10,000	15,000	15,000
Trim hog	20,000	20,000	20,000	25,000
Hogged trim blower (to fuel)	25,000	25,000	25,000	30,000
Saw pneumatic system	25,000	25,000	25,000	30,000
Manual strapper	5,000	5,000	5,000	7,000
Support steel, walkways, etc.	Included	25,000	30,000	30,000
Saw blades	5,000	5,000	5,000	7,000
Miscellaneous chutes	Included	8,000	10,000	10,000
Total Equipment Costs	$ 2,290,000	$ 2,041,000	$ 2,447,000	$ 2,911,000
Total Connected HP	800 [2] (+300 kWh)	1,200	1,420	1,680

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.
2/ For R.F. Preheating.

214

Table 5C.--EQUIPMENT COST DETAILS FOR FORMING, PRESSING, & BOARD TRIMMING
SECTION FOR 112.5- AND 150-MMSF-CAPACITY PLANTS[1]

	Plant Capacity (MMSF 1/2" per annum)		
	112.5		150
	Press Size and Configuration		
	4' x 24' 24 opening	8' x 24' 12 opening	8' x 24' 16 opening
Equipment			
Forming machine	$ 450,000	$ 600,000	$ 600,000
Press, loader, unloader, caul system, weigh scale, B & C separator, board cooler, including cauls & electrical system	2,830,000	3,860,000	4,370,000
Clean-up screw	25,000	30,000	30,000
Mat saw pneumatics	15,000	20,000	20,000
Reject hopper with outfeed	30,000	40,000	40,000
Reject conveyor to bin	30,000	30,000	35,000
Reject bin with outfeed	50,000	50,000	60,000
Press exhaust hood & fans	15,000	18,000	20,000
Press pit clean-up system	15,000	15,000	15,000
Bypass stacker & feeder	35,000	65,000	65,000
Trim saw, including transfers and trim breaker	190,000	270,000	270,000
Saw stacker & outfeed rolls	45,000	70,000	70,000
Trim conveyors	25,000	25,000	25,000
Trim hog	25,000	25,000	25,000
Hogged trim blower (to fuel)	30,000	35,000	40,000
Saw pneumatic system	30,000	35,000	40,000
Manual strapper	10,000	10,000	10,000
Support steel, walkways, etc.	35,000	40,000	40,000
Saw blades	7,000	10,000	10,000
Miscellaneous chutes	15,000	20,000	20,000
Total Equipment Cost	$ 3,907,000	$ 5,268,000	$ 5,805,000
Total Connected HP	1,920	2,800	3,160

[1] Data from USDA, Forest Products Laboratory, Madison, Wisconsin.

| | | Continuous | | 4' x 8' 24 opening | |
		Materials	Labor	Materials	Labor
Mechanical equipment[2]		$ 2,290,000		$ 2,041,000	
Air pollution abatement (filters)		20,000		20,000	
Electrical equipment (PDC's, MCC's, panels & miscellaneous motors)		60,000		60,000	
Installation:					
Mechanical	4,000 hr	10,000	$ 116,000		
	7,000 hr			10,000	$ 203,000 .
Electrical	3,000 hr	25,000	87,000		
	5,000 hr			35,000	145,000
Piping	2,000 hr	15,000	58,000		
	2,500 hr			15,000	72,000
Concrete machinery	150 yd @ $ 80	8,000			
bases, pads, & pits	@ $100		10,000		
	300 yd @ $ 80			24,000	
	@ $100				30,000
Total		$ 2,428,000	$ 271,000	$ 2,205,000	$ 450,000
Total Installed Cost (excluding bldgs)		$ 2,699,000		$ 2,655,000	
Total Connected HP		800 (+300 kWh)		1,200	

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.
2/ See Table 5B.

		Plant Capacity (MMSF 1/2" per annum)			
		37.5		75	
		Press Size and Configuration			
		4' x 16' 12 opening		4' x 16' 24 opening	
		Materials	Labor	Materials	Labor
Mechanical equipment[2]		$ 2,447,000		$ 2,911,000	
Air pollution abatement (filters)		30,000		30,000	
Electrical equipment (PDC's, MCC's, panels & miscellaneous motors)		80,000		90,000	
Installation:					
Mechanical	9,000 hr	10,000	$ 261,000		
	10,000 hr			12,000	$ 290,000
Electrical	6,000 hr	40,000	174,000		
	7,000 hr			45,000	203,000
Piping	3,000 hr	15,000	87,000		
	3,500 hr			25,000	101,000
Concrete machinery	400 yd @ $ 80	32,000			
bases, pads, & pits	@ $100		40,000		
	450 yd @ $ 80			36,000	
	@ $100				45,000
Total		$ 2,654,000	$ 562,000	$ 3,149,000	$ 639,000
Total Installed Cost (excluding bldgs)		$ 3,216,000		$ 3,788,000	
Total Connected HP		1,420		1,680	

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.
2/ See Table 5B.

216

Table 5F.--SECTION COST SUMMARY FOR FORMING, PRESSING, & TRIMMING FOR A 112.5-MMSF-CAPACITY PLANT[1]

| | | Press Size and Configuration | | | |
| | | 4' x 24' 24 opening | | 8' x 24' 12 opening | |
		Materials	Labor	Materials	Labor
Mechanical equipment[2]		$ 3,907,000		$ 5,268,000	
Air pollution abatement (filters)		40,000		40,000	
Electrical equipment (PDC's, MCC's, panels & miscellaneous motors)		100,000		120,000	
Installation:					
Mechanical	11,000 hr	15,000	$ 319,000		
	16,000 hr			18,000	$ 464,000
Electrical	8,000 hr	50,000	232,000		
	10,000 hr			70,000	290,000
Piping	4,000 hr	30,000	116,000		
	5,000 hr			40,000	145,000
Concrete machinery	600 yd @ $ 80	48,000			
bases, pads, & pits	@ $100		60,000		
	800 yd @ $ 80			64,000	
	@ $100				80,000
Total		$ 4,190,000	$ 727,000	$ 5,620,000	$ 979,000
Total Installed Cost (excluding bldgs)		$ 4,917,000		$ 6,599,000	
Total Connected HP		1,920		2,800	

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.
2/ See Table 5B.

Table 5G.--SECTION COST SUMMARY FOR FORMING, PRESSING, & TRIMMING FOR A 150-MMSF-CAPACITY PLANT[1]

| | | Press Size and Configuration | |
| | | 8' x 24' 16 opening | |
		Materials	Labor
Mechanical equipment[2]		$ 5,807,000	
Air pollution abatement (filters)		50,000	
Electrical equipment (PDC's, MCC's, panels & miscellaneous motors)		130,000	
Installation:			
Mechanical	18,000 hr	20,000	$ 522,000
Electrical	11,000 hr	80,000	320,000
Piping	6,000 hr	50,000	174,000
Concrete machinery	900 yd @ $ 80	72,000	
bases, pads, & pits	@ $100		90,000
Total		$ 6,209,000	$ 1,106,000
Total Installed Cost (excluding bldgs)		$ 7,315,000	
Total Connected HP		3,160	

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.
2/ See Table 5B.

217

Table 6A.--STEAM REQUIREMENTS AND BOILER CAPACITY DETERMINATION[1]

Plant Capacity	Raw Material	Site	Press Size and Configuration	Steam Requirements				Boiler Design	
				Pond	Building heat	Press	Total		
MMSF 1/2" per annum						Lb/hr		Lb/hr	Psig
37.5	100% Lathe flakes	S	Continuous		3,000	4,000	7,000	10,000	150
			4' x 8' 24 opening		3,000	6,000	9,000	10,000	300
			4' x 16' 12		4,000	6,000	10,000	15,000	300
		N	Continuous		4,000	4,000	8,000	10,000	150
			4' x 8' 24		5,000	6,000	11,000	15,000	300
			4' x 16' 12		6,000	6,000	12,000	15,000	300
	40% Lathe flakes; 60% Chips	S	Continuous		3,000	4,000	7,000	10,000	150
			4' x 8' 24		3,000	6,000	9,000	10,000	300
			4' x 16' 12		4,000	6,000	10,000	15,000	300
		N	Continuous		4,000	4,000	8,000	10,000	150
			4' x 8' 24		5,000	6,000	11,000	15,000	300
			4' x 16' 12		6,000	6,000	12,000	15,000	300
	40% Tree-length logs; 60% Chips	S	Continuous	3,000	3,000	4,000	10,000	15,000	150
			4' x 8' 24	3,000	3,000	6,000	12,000	15,000	300
			4' x 16' 12	3,000	4,000	6,000	13,000	15,000	300
		N	Continuous	5,000	4,000	4,000	13,000	15,000	150
			4' x 8' 24	5,000	5,000	6,000	16,000	20,000	300
			4' x 16' 12	5,000	6,000	6,000	17,000	20,000	300
75	40% Lathe flakes; 60% Chips	S	4' x 16' 24		5,000	12,000	17,000	20,000	300
		N	4' x 16' 12		8,000	12,000	20,000	25,000	300
	40% Tree-length logs; 60% Chips	S	4' x 16' 24	4,000	5,000	12,000	21,000	25,000	300
		N	4' x 16' 24	7,000	8,000	12,000	27,000	30,000	300
112.5	40% Lathe flakes; 60% Chips	S	4' x 24' 24		6,000	17,000	23,000	25,000	300
			8' x 24' 12		6,000	17,000	23,000	25,000	300
		N	4' x 24' 24		10,000	17,000	27,000	30,000	300
			8' x 24' 12		10,000	17,000	27,000	30,000	300
	40% Tree-length logs; 60% Chips	S	4' x 24' 24	6,000	6,000	17,000	29,000	35,000	300
			8' x 24' 12	6,000	6,000	17,000	29,000	35,000	300
		N	4' x 24' 24	11,000	10,000	17,000	38,000	45,000	300
			8' x 24' 12	11,000	10,000	17,000	38,000	45,000	300
150	40% Lathe flakes; 60% Chips	S	8' x 24' 16		8,000	22,000	30,000	35,000	300
		N	8' x 24' 16		14,000	22,000	36,000	40,000	300
	40% Tree-length logs; 60% Chips	S	8' x 24' 16	8,000	8,000	22,000	38,000	40,000	300
		N	8' x 24' 16	14,000	14,000	22,000	50,000	55,000	300

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.

Table 6B.--SECTION COST SUMMARY FOR BOILER AND FUEL PREPARATION[1]

	Steaming Capacity (Lb/hr)					
	10,000			15,000		
	Material	Labor	Total	Material	Labor	Total
BOILER PRESSURE, 150 Psig						
Furnace	$ 30,000	$ 3,000	$ 33,000	$ 40,000	$ 3,000	$ 43,000
Burner	55,000	14,000	69,000	70,000	16,000	86,000
Air systems	15,000	8,000	25,000	22,000	12,000	34,000
Controls	11,000	5,000	16,000	16,000	8,000	24,000
Pumps, plumbing, & electrical	38,000	17,000	55,000	52,000	22,000	74,000
Total Boiler	149,000	47,000	196,000	200,000	61,000	261,000
Fuel preparation, drying, & feeding	141,000	63,000	204,000	192,000	67,000	259,000
Total Boiler & Fuel Preparation	$ 290,000	$ 110,000	$ 400,000	$ 392,000	$ 138,000	$ 520,000
BOILER PRESSURE, 300 Psig						
Furnace	40,000	3,000	43,000	50,000	5,000	55,000
Burner	65,000	16,000	71,000	70,000	16,000	86,000
Air systems	20,000	12,000	32,000	22,000	12,000	34,000
Controls	16,000	7,000	23,000	16,000	8,000	24,000
Pumps, plumbing, & electrical	53,000	19,000	72,000	62,000	30,000	92,000
Total Boiler	194,000	57,000	251,000	220,000	71,000	291,000
Fuel preparation, drying, & feeding	141,000	63,000	204,000	192,000	67,000	259,000
Total Boiler & Fuel Preparation	$ 335,000	$ 120,000	$ 455,000	$ 412,000	$ 138,000	$ 550,000

[1] Data from USDA, Forest Products Laboratory, Madison, Wisconsin.

219

Table 6C.—SECTION COST SUMMARY FOR BOILER AND FUEL PREPARATION[1]

| | Steaming Capacity (Lb/hr)[2] | | | | | | | | | | | |
| | 20,000 | | | 25,000 | | | 30,000 | | | 35,000 (Field Erected) | | |
	Material	Labor	Total	Material	Labor	Total	Material	Labor	Total	Material	Labor	Total
Furnace	$ 67,000	$ 7,000	$ 74,000	$ 83,000	$ 9,000	$ 92,000	$ 100,000	$ 11,000	$ 111,000	$ 93,000	$ 52,000	$ 145,000
Burner	82,000	18,000	100,000	102,000	22,000	124,000	120,000	25,000	145,000	87,000	35,000	122,000
Air systems	30,000	15,000	45,000	37,000	20,000	57,000	49,000	20,000	69,000	59,000	21,000	80,000
Controls	22,000	9,000	31,000	25,000	13,000	38,000	28,000	14,000	42,000	30,000	15,000	45,000
Pumps, plumbing, & electrical	69,000	30,000	99,000	73,000	32,000	105,000	77,000	34,000	111,000	82,000	37,000	119,000
Total Boiler	270,000	79,000	349,000	320,000	96,000	416,000	374,000	104,000	478,000	351,000	160,000	511,000
Fuel preparation, drying, & feeding	208,000	73,000	281,000	217,000	77,000	294,000	223,000	79,000	302,000	250,000	89,000	339,000
Total Boiler & Fuel Preparation	$ 478,000	$ 152,000	$ 630,000	$ 537,000	$ 173,000	$ 710,000	$ 597,000	$ 183,000	$ 780,000	$ 601,000	$ 249,000	$ 850,000

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.
2/ Boiler pressure 300 psig.

Table 6D.--SECTION COST SUMMARY FOR BOILER AND FUEL PREPARATION SECTION[1]

| | Steaming Capacity (Lb/hr)[2] | | | | | | | | |
| | 40,000 (Field Erected) | | | 45,000 (Field Erected) | | | 55,000 (Field Erected) | | |
	Material	Labor	Total	Material	Labor	Total	Material	Labor	Total
Furnace	$ 105,000	$ 60,000	$ 165,000	$ 121,000	$ 63,000	$ 184,000	$ 160,000	$ 85,000	$ 245,000
Burner	101,000	40,000	141,000	114,000	45,000	159,000	152,000	58,000	210,000
Air systems	68,000	24,000	92,000	77,000	27,000	104,000	101,000	34,000	135,000
Controls	32,000	16,000	48,000	34,000	17,000	51,000	40,000	20,000	60,000
Pumps, plumbing, & electrical	88,000	40,000	128,000	96,000	43,000	139,000	115,000	50,000	165,000
Total boiler	394,000	180,000	574,000	442,000	195,000	637,000	568,000	247,000	815,000
Fuel preparation, drying & feeding	270,000	96,000	366,000	283,000	100,000	383,000	299,000	106,000	405,000
Total Boiler & Fuel Preparation	$ 644,000	$ 276,000	$ 940,000	$ 725,000	$ 295,000	$ 1,020,000	$ 867,000	$ 353,000	$ 1,220,000

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.
2/ Boiler pressure 300 psig.

Table 7A.—SECTION COST SUMMARY FOR AUXILIARY EQUIPMENT, SOUTHERN LOCATION[1]

| | Plant Capacity (MMSF 1/2" per annum) | | | | | | | |
| | 37.5 | | 75 | | 112.5 | | 150 | |
	Materials	Labor	Materials	Labor	Materials	Labor	Materials	Labor
Air compressor	$ 25,000	$ 3,000	$ 35,000	$ 5,000	$ 50,000	$ 10,000	$ 60,000	$ 10,000
Miscellaneous steam, air & water piping	30,000	25,000	40,000	30,000	50,000	40,000	60,000	50,000
Sanitary system	10,000	10,000	15,000	15,000	20,000	20,000	25,000	25,000
Cooling tower	5,000	3,000	8,000	4,000	10,000	5,000	12,000	6,000
Standby gas or oil fuel system	3,000	2,000	5,000	3,000	6,000	4,000	7,000	5,000
Electrical transformer & HV power distribution	30,000	5,000	40,000	10,000	50,000	20,000	60,000	30,000
Shop equipment including knife grinders	20,000	5,000	40,000	5,000	50,000	8,000	60,000	10,000
Spare parts allowance	60,000	–	100,000	–	120,000	–	150,000	–
Outside lighting	7,000	3,000	10,000	5,000	12,000	8,000	15,000	5,000
Laboratory & office equipment	15,000	2,000	20,000	3,000	20,000	3,000	22,000	5,000
Lift trucks	80,000	–	100,000	–	140,000	–	160,000	–
Effluent treatment (Allowance)	10,000	5,000	15,000	8,000	18,000	10,000	20,000	12,000
Miscellaneous concrete bases, pads, etc.	4,000	5,000	6,000	8,000	8,000	10,000	10,000	12,000
Total	$ 299,000	$ 72,000	$ 434,000	$ 99,000	$ 554,000	$ 138,000	$ 661,000	$ 170,000
Total Installed Cost	$ 371,000		$ 533,000		$ 692,000		$ 831,000	
Total Connected HP	100		150		200		250	

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.

Table 7B.—SECTION COST SUMMARY FOR AUXILIARY EQUIPMENT, NORTHERN LOCATION[1]

| | Plant Capacity (MMSF 1/2" per annum) | | | | | | | |
| | 37.5 | | 75 | | 112.5 | | 150 | |
	Materials	Labor	Materials	Labor	Materials	Labor	Materials	Labor
Air compressor	$ 25,000	$ 3,000	$ 35,000	$ 5,000	$ 50,000	$ 10,000	$ 60,000	$ 10,000
Miscellaneous steam, air & water piping	35,000	30,000	45,000	35,000	60,000	50,000	70,000	60,000
Sanitary system	10,000	10,000	12,000	12,000	15,000	15,000	20,000	20,000
Cooling tower	5,000	3,000	8,000	4,000	10,000	5,000	12,000	6,000
Electrical transformer & HV power distribution	30,000	5,000	40,000	10,000	50,000	20,000	60,000	30,000
Shop equipment including knife grinders	20,000	5,000	40,000	5,000	50,000	8,000	60,000	10,000
Spare parts allowance	60,000	–	100,000	–	120,000	–	150,000	–
Outside lighting	10,000	5,000	15,000	8,000	20,000	12,000	25,000	15,000
Laboratory & office equipment	15,000	2,000	20,000	3,000	20,000	3,000	22,000	5,000
Lift trucks	80,000	–	100,000	–	140,000	–	160,000	–
Effluent treatment (Allowance)	12,000	7,000	18,000	10,000	20,000	12,000	25,000	15,000
Miscellaneous concrete bases, pads, etc.	6,000	8,000	8,000	10,000	10,000	12,000	12,000	14,000
Total	$ 308,000	$ 78,000	$ 441,000	$102,000	$ 565,000	$ 147,000	$ 676,000	$ 185,000
Total Installed Cost	$ 386,000		$ 543,000		$ 712,000		$ 861,000	
Total Connected HP	100		150		200		250	

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.

Table 8A.--CAPITAL COST SUMMARY FOR A 37.5-MMSF-CAPACITY PLANT, SOUTHERN LOCATION[1]

	Material	Labor	Subtotal	Total
Log handling & flaking	-	-	-	
Lathe flake handling & storage[2]	$ 424,000	$ 83,000	$ 507,000	
Chip handling & flaking	-	-	-	
Drying, screening & blending	808,000	180,000	988,000	
Forming, pressing & trimming[3]	2,205,000	450,000	2,655,000	
Auxiliary equipment	299,000	72,000	371,000	
Boiler & fuel preparation	335,000	120,000	455,000	
Subtotal	$ 4,071,000	$ 905,000	$ 4,976,000	$ 4,976,000
Freight allowance				180,000
				$ 5,156,000
Buildings & structures	302,000	281,000	583,000	
Site development & land purchase	175,000	143,000	318,000	
Subtotal	$ 477,000	$ 424,000	$ 901,000	901,000
				$ 6,057,000
Engineering, purchasing & construction management (~ 10%)				603,000
Subtotal				$ 6,660,000
Contingency allowance (~ 5.5%-7.7%)				460,000
Total Construction Costs[4]				$ 7,100,000

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.
2/ Raw material 100% lathe flakes.
3/ Press size, 4' x 8' x 24 openings.
4/ Does not include start-up expenses, interest during construction and working capital.

Table 8B.--BUILDING STRUCTURES & SITE DEVELOPMENT COSTS FOR A
37.5-MMSF-CAPACITY PLANT, SOUTHERN LOCATION[1],[2]

	Press Size and Configuration					
	Continuous		4' x 8' 24 opening		4' x 16' 12 opening	
	Materials	Labor	Materials	Labor	Materials	Labor
Building Area (ft^2)						
Woodyard, flaking, drying	2,000		2,000		2,000	
Blending, forming, pressing, trim	25,000		25,000		33,000	
Warehouse	25,000		25,000		30,000	
Misc. (shops, offices, boiler, etc.)	2,000		2,000		2,000	
Total Building Area (ft^2)	54,000		54,000		67,000	
Buildings Costs[2]	$ 302,000	$ 280,000	$ 302,000	$ 280,000	$ 375,000	$ 348,000
Site Development						
Site clearing & grading	15,000	30,000	15,000	30,000	16,000	32,000
Roads	10,000	15,000	10,000	15,000	15,000	20,000
Misc. outside slabs	5,000	8,000	5,000	8,000	8,000	10,000
Rail spur	10,000	10,000	10,000	10,000	12,000	12,000
Sewers & drainage	10,000	15,000	10,000	15,000	12,000	16,000
Fire loop, pumps, hydrants	35,000	30,000	35,000	30,000	40,000	35,000
Fire pond allowance	15,000	15,000	15,000	15,000	18,000	18,000
Water well or connection	15,000	20,000	15,000	20,000	15,000	20,000
Land purchase allow. @ $2,000/acre	60,000		60,000		80,000	
Total Site Development	$ 175,000	$ 143,000	$ 175,000	$ 143,000	$ 216,000	$ 163,000
Total Buildings & Site Development	$ 477,000	$ 423,000	$ 477,000	$ 423,000	$ 591,000	$ 511,000

1/ Raw material 100% lathe flakes.
2/ Bldgs. with slabs, footings, heating, sprinklers, air conditioning & finishing: Material
average cost/ft^2 = $5.60; Labor @ average cost/ft^2 = $5.20.

Table 9A.--CAPITAL COST SUMMARY FOR A 75-MMSF-CAPACITY PLANT, NORTHERN LOCATION[1]

	Material	Labor	Subtotal	Total
Log handling & flaking	-	-	-	
Lathe flake handling & storage[2]	$ 334,000	$ 89,000	$ 423,000	
Chip handling & flaking[2]	1,018,000	194,000	1,212,000	
Drying, screening & blending	1,366,000	290,000	1,656,000	
Forming, pressing & trimming[3]	3,149,000	639,000	3,788,000	
Auxiliary equipment	441,000	102,000	543,000	
Boiler & fuel preparation	537,000	173,000	710,000	
Subtotal	$ 6,845,000	$ 1,487,000	$ 8,332,000	$ 8,332,000
Freight allowance				298,000
				$ 8,630,000
Buildings & structures	765,000	714,000	1,479,000	
Site development & land purchase	258,000	210,000	468,000	
Subtotal	$ 1,023,000	$ 924,000	$ 1,947,000	$ 1,947,000
				$ 10,577,000
Engineering, purchasing & construction management (~ 10%)				1,003,000
Subtotal				$ 11,580,000
Contingency allowance (~ 5.5%-7.7%)				720,000
Total Construction Costs[4]				$ 12,300,000

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.
2/ Raw material 40% lathe flakes; 60% chips.
3/ Press size, 4' x 16' x 24 opening.
4/ Does not include start-up expenses, interest during construction and working capital.

Table 9B.--BUILDING STRUCTURES & SITE DEVELOPMENT COSTS FOR A
75-MMSF-CAPACITY PLANT, NORTHERN LOCATION[1]

	Raw Material			
	40% Lathe Flakes; 60% Chips		40% Tree-length Logs; 60% Chips	
	Materials	Labor	Materials	Labor
Building Area (ft^2)				
Woodyard, flaking, drying	10,000		35,000	
Blending, forming, pressing, trim	45,000		45,000	
Warehouse	45,000		45,000	
Misc. (shops, offices, boiler, etc.	2,000		2,000	
Total Building Area (ft^2)	102,000		127,000	
Building Costs[2]	$ 765,000	$ 714,000	$ 960,000	$ 896,000
Site Development				
Site clearing & grading	20,000	40,000	25,000	45,000
Roads	18,000	25,000	18,000	25,000
Misc. outside slabs	12,000	15,000	12,000	15,000
Rail spur	15,000	15,000	15,000	15,000
Sewers & drainage	15,000	20,000	15,000	20,000
Fire loop, pumps, hydrants	55,000	50,000	60,000	55,000
Fire pond allowance	25,000	25,000	30,000	30,000
Water well or connection	18,000	20,000	18,000	20,000
Land purchase allow. @ $2,000/acre	80,000	-	120,000	-
Total Site Development	$ 258,000	$ 210,000	$ 313,000	$ 225,000
Total Buildings & Site Development	$ 1,023,000	$ 924,000	$ 1,273,000	$ 1,121,000

1/ Press size and configuration, 4' x 16' x 24 openings.
2/ Bldgs. with slabs, footings, heating, sprinklers, air conditioning & finishing: Materials
@ average cost/ft^2 = $7.50; Labor @ average cost/ft^2 = $7.00.

Table 10A.--CAPITAL COST SUMMARY FOR A 112.5-MMSF-CAPACITY PLANT, NORTHERN LOCATION[1]

	Material	Labor	Subtotal	Total
Log handling & flaking[2]	$ 1,608,000	$ 415,000	$ 2,023,000	
Lathe flake handling & storage	-	-	-	
Chip handling & flaking[2]	1,274,000	250,000	1,524,000	
Drying, screening & blending	1,808,000	368,000	2,176,000	
Forming, pressing & trimming[3]	5,620,000	979,000	6,599,000	
Auxiliary equipment	565,000	147,000	712,000	
Boiler & fuel preparation	725,000	295,000	1,020,000	
Subtotal	$ 11,600,000	$ 2,454,000	$ 14,054,000	$ 14,054,000
Freight allowance				472,000
				$ 14,526,000
Buildings & structures	1,387,000	1,292,000	2,679,000	
Site development & land purchase	450,000	285,000	735,000	
Subtotal	$ 1,837,000	$ 1,577,000	$ 3,414,000	$ 3,414,000
				$ 17,940,000
Engineering, purchasing & constructure management (~ 10%)				1,760,000
Subtotal				$ 19,700,000
Contingency allowance (~ 5.5%-7.7%)				1,300,000
Total Construction Costs[4]				$ 21,000,000

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.
2/ Raw material 40% tree-length logs; 60% chips.
3/ Press size and configuration, 8' x 24' x 12 openings.
4/ Does not include start-up expenses, interest during construction and working capital.

Table 10B.--BUILDING STRUCTURES & SITE DEVELOPMENT COSTS FOR A
112.5-MMSF-CAPACITY PLANT, NORTHERN LOCATION[1]

	Press Size and Configuration			
	4' x 24' 24 openings		8' x 24' 12 openings	
	Materials	Labor	Materials	Labor
Building Area (ft^2)				
Woodyard, flaking, drying	56,000		56,000	
Blending, forming, pressing, trim	60,000		65,000	
Warehouse	60,000		65,000	
Misc. (shops, offices, boiler, etc.)	4,000		4,000	
Total Building Area (ft^2)	180,000		190,000	
Building Costs[2]	$ 1,314,000	$ 1,224,000	$ 1,387,000	$ 1,292,000
Site Development				
Site clearing & grading	35,000	55,000	35,000	55,000
Roads	25,000	30,000	25,000	30,000
Misc. outside slabs	18,000	20,000	20,000	25,000
Rail spur	20,000	20,000	20,000	20,000
Sewers & drainage	25,000	30,000	25,000	30,000
Fire loop, pumps, hydrants	65,000	60,000	70,000	65,000
Fire pond allowance	32,000	32,000	35,000	35,000
Water well or connection	20,000	25,000	20,000	25,000
Land purchase allow. @ $2,000/acre	200,000		200,000	
Total Site Development	$ 440,000	$ 272,000	$ 450,000	$ 285,000
Total Buildings & Site Development	$ 1,754,000	$ 1,496,000	$ 1,837,000	$ 1,577,000

1/ Raw material 40% tree-length logs; 60% chips.
2/ Bldgs. with slabs, footings, heating, sprinklers, air conditioning & finishing:
Materials @ average cost/ft^2 = $7.30; Labor @ average cost/ft^2 = $6.80.

Table 11A.--SUMMARY OF CAPITAL COSTS[1]

Plant Capacity	Site	Press Size and Configuration	100% Lathe flakes	40% Lathe flakes; 60% Chips	40% Tree-length logs; 60% Chips
			Raw Material		
MMSF 1/2" per annum			- - - - - - - - - - $/MSF 1/2" - - - - - - - - - - - -		
37.5	S	Continuous 4' x 8' 24	$ 7,100,000	$ 8,200,000	$ 9,950,000
		opening	7,100,000	8,200,000	9,900,000
		4' x 16' 12	8,100,000	9,200,000	10,800,000
	N	Continuous	7,450,000	8,550,000	10,400,000
		4' x 8' 24	7,560,000	8,670,000	10,500,000
		4' x 16' 12	8,550,000	9,600,000	11,600,000
75	S	4' x 16' 24		11,700,000	13,550,000
	N	4' x 16' 24		12,300,000	14,600,000
112.5	S	4' x 24' 24		14,900,000	17,000,000
		8' x 24' 12		17,000,000	19,200,000
	N	4' x 24' 24		15,800,000	18,700,000
		8' x 24' 12		18,000,000	21,000,000
150	S	8' x 24' 16		20,000,000	22,400,000
	N	8' x 24' 16		21,500,000	24,500,000

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.

Table 11B.--SUMMARY OF CAPITAL COSTS PER UNIT OF OUTPUT[1]

Plant Capacity	Site	Press Size and Configuration	100% Lathe flakes	40% Lathe flakes; 60% Chips	40% Tree-length logs; 60% Chips
			Raw Material		
MMSF 1/2" per annum			- - - - - - - - - - $/MSF 1/2" - - - - - - - - - - - -		
37.5	S	Continuous 4' x 8' 24	$ 142.00	$ 164.00	$ 199.00
		opening	142.00	164.00	198.00
		4' x 16' 12	162.00	184.00	216.00
	N	Continuous	149.00	171.00	208.00
		4' x 8' 24	151.00	173.00	210.00
		4' x 16' 12	170.00	192.00	232.00
75	S	4' x 16' 24		117.00	135.00
	N	4' x 16' 24		123.00	146.00
112.5	S	4' x 24' 24		99.00	113.00
		8' x 24' 12		113.00	128.00
	N	4' x 24' 24		105.00	124.00
		8' x 24' 12		120.00	140.00
150	S	8' x 24' 16		100.00	112.00
	N	8' x 24' 16		107.00	122.00

1/ Data from USDA, Forest Products Laboratory, Madison, Wisconsin.

APPENDIX B.--ESTIMATES OF CAPITAL INVESTMENT COSTS FOR FOUR SIZES OF STRUCTURAL FLAKEBOARD FACILITIES

In April 1976, the Forest Products Laboratory (U.S. Department of Agriculture, Forest Service) at Madison, Wisconsin, retained Columbia Engineering International, Ltd. of Eugene, Oregon, to investigate the capital costs of plants designed to produce structural-grade flakeboards. The plant designs and capital costs developed by Columbia's study were based partly on the data supplied from Forest Service research and partly from Columbia's past experience in the design, construction, and operation of structural-grade, as well as industrial-grade, particleboard plants.

Columbia's study resulted in the definition of basic or standard plant components which may be utilized in the design of a wide range of plant design parameters. In the pages that follow, the selection of plant configurations used for economic analysis are summarized in terms of their construction costs (1976 basis) and depreciation schedules. Facility costs in this section include an additional 10 percent of costs

estimated by Columbia Engineering to cover construction-period interest and miscellaneous tax costs. This selection of plant designs represents facilities with annual output capacities ranging from 37.5 MMSF, 1/2-inch basis, to 150 MMSF, 1/2-inch basis. Additionally, each facility size is represented by a design suitable for siting in intemperate climatic conditions typical of northern latitudes of the United States (excluding Alaska), designated Northern, and for siting in temperate climates typical of the southern latitudes of the United States, designated Southern. The difference in facilities designed for Northern and Southern sites is found in the amount of shelter and thermal protection provided for raw materials in storage and processing operations. Each facility is also designed for the utilization of roundwood, chips and/or flakes. Operating requirements and cost estimates used for the economic analysis of each facility are given in Appendix C.

Table 1.--CAPITAL COSTS AND DEPRECIATION ALLOWANCES FOR A 37.5-MMSF-CAPACITY PLANT USING 100% FLAKES[1]

	Capital Costs	Depreciation					
	1976	1976	1977	1978	1979	1980	1981-1985
	-------------------------------- Thousand $ ----------------------------------						
NORTHERN SITES							
Land (30 acres)[2]	----	----	----	----	----	----	----
Land improvements	288	14.4	14.4	14.4	14.4	14.4	14.4
Buildings	840	18.7	18.7	18.7	18.7	18.7	18.7
Processing equipment[3]	6,988	1,257.8	1,006.3	805.0	644.0	515.2	412.2
Mobile equipment							
1st 5 years	140	25.2	25.2	25.2	25.2	25.2	
2nd 5 years						(178.7)	34.7
Totals	8,316	1,316.1	1,122.9	863.3	702.3	573.5	480.0
SOUTHERN SITES							
Land (30 acres)[2]	----	----	----	----	----	----	----
Land improvements	258	12.9	12.9	12.9	12.9	12.9	12.9
Buildings	582	12.9	12.9	12.9	12.9	12.9	12.9
Processing equipment[3]	6,791	1,222.4	977.9	782.3	625.9	500.7	400.5
Mobile equipment							
1st 5 years	140	25.2	25.2	25.2	25.2	25.2	
2nd 5 years						(178.7)	34.7
Totals	7,831	1,273.4	1,028.9	833.3	676.9	551.7	461.0

[1] Annual wood requirement, 2.6 to 3.3 million ft^3.

[2] See Appendix C for land cost estimates for each site.

[3] Press size and configuration, 4' x 8' 24 openings.

Table 2.--CAPITAL COSTS AND DEPRECIATION ALLOWANCES FOR A 37.5-MMSF-CAPACITY PLANT USING 40% FLAKES; 60% CHIPS[1]

	Capital Costs	Depreciation					
	1976	1976	1977	1978	1979	1980	1981-1985
	Thousand $						
NORTHERN SITES							
Land (30 acres)[2]	----	-----	----	----	----	----	----
Land improvements	292	14.6	14.6	14.6	14.6	14.6	14.6
Buildings	885	19.6	19.6	19.6	19.6	19.6	19.6
Processing equipment[3]	8,060	1,450.8	1,160.6	928.5	742.8	594.2	475.4
Mobile equipment							
1st 5 years	240	43.2	43.2	43.2	43.2	43.2	
2nd 5 years						(306.3)	59.5
Totals	9,537	1,528.2	1,238.0	1,005.9	820.2	671.6	569.1
SOUTHERN SITES							
Land (30 acres)[2]	----	----	----	----	----	----	----
Land improvements	266	13.3	13.3	13.3	13.3	13.3	13.3
Buildings	615	13.7	13.7	13.7	13.7	13.7	13.7
Processing equipment[3]	7,839	1,411.0	1,128.8	903.1	722.4	578.0	462.4
Mobile equipment							
1st 5 years	240	43.2	43.2	43.2	43.2	43.2	
2nd 5 years						(306.3)	59.5
Totals	9,020	1,481.2	1,1990.0	973.3	792.6	648.2	548.9

[1] Annual wood requirement, 2.6 to 3.3 million ft^3.

[2] See Appendix C for land cost estimates for each site.

[3] Press size and configuration, 4' x 8' 24 openings.

Table 3.--CAPITAL COSTS AND DEPRECIATION ALLOWANCES FOR A 37.5-MMSF-CAPACITY PLANT USING 40% LOGS; 60% CHIPS[1]

	Capital Costs	Depreciation					
	1976	1976	1977	1978	1979	1980	1981-1985
	Thousand $						
NORTHERN SITES							
Land (35 acres)[2]	----	----	----	----	----	----	----
Land improvements	301	15.1	15.1	15.1	15.1	15.1	15.1
Buildings	1,005	22.3	22.3	22.3	22.3	22.3	22.3
Processing equipment[3]	9,759	1,756.6	1,405.3	1,124.2	899.4	719.5	575.6
Mobile equipment							
1st 5 years	415	74.7	74.7	74.7	74.7	74.7	
2nd 5 years						(529.7)	102.8
Totals	11,550	1,868.7	1,517.4	1,236.3	1,011.5	831.6	715.8
SOUTHERN SITES							
Land (35 acres)[2]	----	----	----	----	----	----	----
Land improvements	277	13.9	13.9	13.9	13.9	13.9	13.9
Buildings	615	13.7	13.7	13.7	13.7	13.7	13.7
Processing equipment[3]	9,513	1,712.3	1,369.9	1,095.9	876.7	701.4	561.1
Mobile equipment							
1st 5 years	415	74.7	74.7	74.7	74.7	74.7	
2nd 5 years						(529.7)	102.8
Totals	10,890	1,814.6	1,472.2	1,198.2	979.0	803.7	691.5

[1] Annual wood requirement, 2.6 to 3.3 million ft^3.

[2] See Appendix C for land cost estimates for each site.

[3] Press size and configuration, 4' x 8' 24 openings.

Table 4.--CAPITAL COSTS AND DEPRECIATION ALLOWANCES FOR A   75-MMSF-CAPACITY PLANT

USING 40% FLAKES; 60% CHIPS

	Capital Costs	Depreciation					
	1976	1976	1977	1978	1979	1980	1981-1985

-------------------------------------Thousand $------------------------------------

NORTHERN SITES

d (40 acres)²/	----	----	----	----	----	----	----
d improvements	388	19.4	19.4	19.4	19.4	19.4	19.4
ldings	1,479	32.9	32.9	32.9	32.9	32.9	32.9
cessing equipment³/	11,333	2,039.9	1,632.0	1,305.6	1,044.4	835.6	668.4
ile equipment							
st 5 years	250	45	45	45	45	45	
nd 5 years						319.1	61.9
Totals	13,530	2,137.2	1,729.3	1,402.9	1,141.7	932.9	782.6

SOUTHERN SITES

d (40 acres)²/	----	----	----	----	----	----	----
d improvements	373	18.7	18.7	18.7	18.7	18.7	18.7
ldings	1,029	22.9	22.9	22.9	22.9	22.9	22.9
cessing equipment³/	11,138	2,004.8	1,603.9	1,283.1	1,026.5	821.2	656.9
ile equipment							
st 5 years	250	45	45	45	45	45	
nd 5 years						319.1	61.9
Totals	12,870	2,091.4	1,690.5	1,369.7	1,113.1	907.8	760.4

¹/ Annual wood requirement, 5.2 to 6.5 million ft³.

²/ See Appendix C for land cost estimates for each site.

³/ Press size and configuration, 4' x 16' 24 openings.

Table 5.--CAPITAL COSTS AND DEPRECIATION ALLOWANCES FOR A 75-MMSF-CAPACITY PLANT

USING 40% LOGS; 60% CHIPS¹/

	Capital Costs	Depreciation					
	1976	1976	1977	1978	1979	1980	1981-1985

-------------------------------------Thousand $------------------------------------

NORTHERN SITES

d (60 acres)²/	----	:	----	----	----	----	----	----
d improvements	418	:	20.9	20.9	20.9	20.9	20.9	20.9
ldings	1,856	:	41.2	41.2	41.2	41.2	41.2	41.2
cessing equipment³/	13,241	:	2,383.4	1,906.7	1,525.4	1,220.3	976.2	780.9
ile equipment		:						
st 5 years	425	:	76.5	76.5	76.5	76.5	76.5	
nd 5 years		:					542.4	105.3
Totals	16,060	:	2,522.0	2,045.3	1,664.0	1,358.9	1,114.8	948.3

SOUTHERN SITES

d (60 acres)²/	----	:	----	----	----	----	----	----
d improvements	383	:	19.2	19.2	19.2	19.2	19.2	19.2
ldings	1,076	:	23.9	23.9	23.9	23.9	23.9	23.9
cessing equipment³/	12,894	:	2,320.9	1,856.7	1,485.4	1,188.3	950.6	760.5
ile equipment		:						
st 5 years	425	:	76.5	76.5	76.5	76.5	76.5	
nd 5 years		:					542.4	105.3
Totals	14,898	:	2,440.5	1,976.3	1,605.0	1,307.9	1,070.2	908.9

¹/ Annual wood requirement, 5.2 to 6.5 million ft³.

²/ See Appendix C for land cost estimates for each site.

³/ Press size and configuration, 4' x 16' 24 openings.

Table 6.--CAPITAL COSTS AND DEPRECIATION ALLOWANCES FOR A 112.5-MMSF-CAPACITY PLANT USING 40% FLAKES; 60% CHIPS[1]

	Capital Costs	Depreciation					
	1976	1976	1977	1978	1979	1980	1981-1985
	Thousand $						
	NORTHERN SITES						
Land (70 acres)[2]	----	----	----	----	----	----	----
Land improvements	461	23.1	23.1	23.1	23.1	23.1	23.1
Buildings	2,045	45.5	45.5	45.5	45.5	45.5	45.5
Processing equipment[3]	14,444	2,599.9	2,079.9	1,663.9	1,331.1	1,064.9	851.9
Mobile equipment							
1st 5 years	290	52.2	52.2	52.2	52.2	52.2	
2nd 5 years						(370.1)	71.8
Totals	17,380	2,720.7	2,200.7	1,784.7	1,451.9	1,185.7	992.3
	SOUTHERN SITES						
Land (70 acres)[2]	----	----	----	----	----	----	----
Land improvements	427	21.4	21.4	21.4	21.4	21.4	21.4
Buildings	1,360	30.2	30.2	30.2	30.2	30.2	30.2
Processing equipment[3]	14,173	2,551.1	2,040.9	1,632.7	1,306.2	1,044.9	835.6
Mobile equipment							
1st 5 years	290	52.2	52.2	52.2	52.2	52.2	
2nd 5 years						(370.1)	71.8
Totals	16,390	2,654.9	2,144.7	1,736.5	1,410.0	1,148.7	959.0

[1] Annual wood requirement, 7.7 to 9.7 million ft^3.

[2] See Appendix C for land cost estimates for each site.

[3] Press size and configuration, 4' x 24' 24 openings.

Table 7.--CAPITAL COSTS AND DEPRECIATION ALLOWANCES FOR A 112.5-MMSF-CAPACITY PLANT USING 40% LOGS; 60% CHIPS[1]

	Capital Costs	Depreciation					
	1976	1976	1977	1978	1979	1980	1981-1985
	Thousand $						
	NORTHERN SITES						
Land (100 acres)[2]	----	----	----	----	----	----	----
Land improvements	512	25.6	25.6	25.6	25.6	25.6	25.6
Buildings	2,538	56.4	56.4	56.4	56.4	56.4	56.4
Processing equipment[3]	16,855	3,033.9	2,427.1	1,941.7	1,553.4	1,242.7	994.1
Mobile equipment							
1st 5 years	465	83.7	83.7	83.7	83.7	83.7	
2nd 5 years						(593.5)	115.2
Totals	20,570	3,199.6	2,592.8	2,107.4	1,719.1	1,408.4	1,191.3
	SOUTHERN SITES						
Land (100 acres)[2]	----	----	----	----	----	----	----
Land improvements	473	23.7	23.7	23.7	23.7	23.7	23.7
Buildings	1,391	30.9	30.9	30.9	30.9	30.9	30.9
Processing equipment[3]	16,171	2,910.8	2,328.6	1,862.9	1,490.3	1,192.3	953.8
Mobile equipment							
1st 5 years	465	83.7	83.8	83.7	83.7	83.7	
2nd 5 years						(593.5)	115.2
Totals	18,700	3,049.1	2,466.9	2,001.2	1,628.6	1,330.6	1,092.1

[1] Annual wood requirement, 7.7 to 9.7 million ft^3.

[2] See Appendix C for land cost estimates for each site.

[3] Press size and configuration, 4' x 24' 24 openings.

Table 8.--CAPITAL COSTS AND DEPRECIATION ALLOWANCES FOR A 150-MMSF-CAPACITY PLANT USING 40% FLAKES; 60% CHIPS[1]

	Capital Costs	Depreciation					
	1976	1976	1977	1978	1979	1980	1981-1985
	Thousand $						
NORTHERN SITES							
Land (100 acres)[2]	----	----	----	----	----	----	----
Land improvements	625	31.3	31.3	31.3	31.3	31.3	31.3
Buildings	2,730	50.7	50.7	50.7	50.7	50.7	50.7
Processing equipment[3]	19,785	3,561.3	2,849.0	2,279.2	1,823.4	1,458.7	1,167.0
Mobile equipment							
1st 5 years	310)	55.8	55.8	55.8	55.8	55.8	
2nd 5 years						395.7	76.8
Totals	23,650	3,699.1	2,986.8	2,417.0	1,961.2	1,596.5	1,325.8
SOUTHERN SITES							
Land (100 acres)[2]	----	----	----	----	----	----	----
Land improvements	545	27.3	27.3	27.3	27.3	27.3	27.3
Buildings	1,679	37.3	37.3	37.3	37.3	37.3	37.3
Processing equipment[3]	18,993	3,418.7	2,735.0	2,188.0	1,750.4	1,400.3	1,120.3
Mobile equipment							
1st 5 years	310	55.8	55.8	55.8	55.8	55.8	
2nd 5 years						395.7	76.8
Totals	21,727	3,539.1	2,835.4	2,308.4	1,870.8	1,520.7	1,261.7

[1] Annual wood requirement, 10.0 to 12.6 million ft^3.

[2] See Appendix C for land cost estimates for each site.

[3] Press size and configuration, 8' x 24' 16 openings.

Table 9.--CAPITAL COSTS AND DEPRECIATION ALLOWANCES FOR A 150-MMSF-CAPACITY PLANT USING 40% LOGS; 60% CHIPS[1]

	Capital Costs	Depreciation					
	1976	1976	1977	1978	1979	1980	1981-1985
	Thousand $						
NORTHERN SITES							
Land (150 acres)[2]	----	----	----	----	----	----	----
Land improvements	695	34.8	34.8	34.8	34.8	34.8	34.8
Buildings	3,220	71.6	71.6	71.6	71.6	71.6	71.6
Processing equipment[3]	22,200	3,996.0	3,196.8	2,557.4	2,046.0	1,636.8	1,309.4
Mobile equipment							
1st 5 years	535	96.3	96.3	96.3	96.3	96.3	
2nd 5 years						682.8	132.5
Totals	26,950	4,198.7	3,399.5	2,760.1	2,248.7	1,839.5	1,548.3
SOUTHERN SITES							
Land (150 acres)[2]	----	----	----	----	----	----	----
Land improvements	610	34.8	34.8	34.8	34.8	34.8	34.8
Buildings	1,720	38.2	38.2	38.2	38.2	38.2	38.2
Processing equipment[3]	21,159	3,808.6	3,046.9	2,437.5	1,950.0	1,560.0	1,248.0
Mobile equipment							
1st 5 years	535	96.3	96.3	96.3	96.3	96.3	
2nd 5 years						682.8	132.5
Totals	24,324	3,977.9	3,216.2	2,606.8	2,119.3	1,729.3	1,453.5

[1] Annual wood requirement, 10.0 to 12.6 million ft^3.

[2] See Appendix C for land cost estimates for each site.

[3] Press size and configuration, 8' x 24' 16 openings.

Table 1.--PERSONNEL REQUIREMENTS

	Press Size			
	4' x 8'	4' x 16'	4' x 24'	8' x 24'
	Plant Capacity (MMSF, 1/2" per annum)			
	37.5	75	112.5	150
	Number of persons			
Administrative personnel				
Manager	1	1	1	1
Supervisor	1	1	1	1
Engineer	—	1	1	1
Office manager	1	1	1	1
Technical director	1	1	1	1
Shipper	1	1	1	1
Purchasing agent	1	1	1	1
Clerical	4	4	4	4
Foremen	3	3	5	6
Total	13	14	16	17
Processing personnel[1]				
100% flakes				
Skilled labor	29			
Unskilled labor	4			
Total	33			
40% flakes; 60% chips				
Skilled labor	31	34	43	49
Unskilled labor	4	6	6	8
Total	35	40	49	57
40% log;, 60% chips				
Skilled labor	39	43	53	63
Unskilled labor	5	8	11	12
Total	44	51	64	75

1/ Maintenance personnel requirements are not included. All maintenance and repair costs are included in factory overhead costs at 6.5% of facilities capital cost, excluding land cost.

Table 2.--HEAT-ENERGY REQUIREMENTS

	Northern Site	Southern Site
	MM Btu/lb evaporated H_2O	
Dryer heat	0.0020	0.0020
	MM Btu/ft^3 finished product	
Thaw-pond heat	0.0192	0.0128
Press heat	0.0400	0.0400
Building heat	0.0144	0.0064

Table 3.--PERSONNEL, CHEMICAL, ENERGY, AND LAND COSTS, 1976 BASIS

Northern Sites

	St. Anthony, Idaho	Virginia, Minnesota	Western Montana	LaGrande, Oregon	Medford, Oregon	Southern Vermont	Longview, Washington
Personnel costs							
Administrative personnel 1/				$/Yr			
Manager	30,000	30,000	30,000	30,000	30,000	30,000	30,000
Supervisor	25,500	25,000	25,000	25,000	25,000	25,000	25,000
Engineer	15,000	15,000	15,000	15,000	15,000	15,000	15,000
Office manager	12,000	12,000	12,000	12,000	12,000	12,000	12,000
Technical director	12,000	12,000	12,000	12,000	12,000	12,000	12,000
Shipper	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Purchasing agent	12,000	12,000	12,000	12,000	12,000	12,000	12,000
Clerical	6,000	7,000	10,820	7,400	7,400	7,400	7,400
Foremen	13,500	11,560	13,500	14,400	14,400	12,000	14,400
Processing personnel 1/				$/Hr			
Skilled labor	5.50	5.80	5.80	5.90	5.90	4.45	5.90
Unskilled labor	5.00	5.25	4.93	5.10	5.10	4.00	5.10
Chemical costs				$.00/Lb solids			
Liquid phenolic resin	29	29.	28	29	29	33	29
Emulsified wax	19	19	19	19	19	19	19
Energy costs				$.00/kWh			
Electricity	1.25	2.0	1.25	1.5	1.25	2.5	1.5
Oil	12.50	14.25	12.50	$/6 Million Btu 15.50	15.50	15.50	15.50
Land costs				$/Acre			
	1,000	1,500	10,000	5,000	5,000	2,000	5,000

1/ 30% added to cover fringe benefits.

Table 3.--PERSONNEL, CHEMICAL, ENERGY, AND LAND COSTS, 1976 BASIS (Cont.)

	Northern Sites			Southern Sites					
	Northern West Virginia	Laramie, Wyoming	Arcata California	South Central Georgia	Cornish Mississippi	Southern Missouri	Oak Ridge, Tennessee	Southeastern Tennessee	East Texas
Personnel costs									
Administrative personnel [1]					$/Yr				
Manager	30,000	30,000	30,000	26,000	25,000	25,000	25,000	25,000	25,000
Supervisor	30,000	25,000	25,000	21,000	18,000	18,000	18,000	20,000	18,000
Engineer	12,000	15,000	15,000	12,000	12,000	12,000	12,000	12,000	12,000
Office manager	10,000	12,000	12,000	11,000	10,000	10,000	10,000	10,000	10,000
Technical director	10,000	12,000	12,000	11,000	10,000	10,000	10,000	10,000	10,000
Shipper	8,000	10,000	10,000	9,000	8,000	8,000	8,000	7,900	8,000
Purchasing agent	10,000	12,000	12,000	10,000	10,000	10,000	10,000	10,000	10,000
Clerical	7,700	5,800	7,400	8,160	6,320	9,800	6,800	7,900	9,800
Foremen	12,000	14,000	14,400	14,500	12,000	14,000	12,000	15,000	14,000
Processing personnel [1]					$/Hr				
Skilled labor	2.83	4.35	6.20	4.10	3.40	4.90	4.00	4.00	4.90
Unskilled labor	2.68	4.05	5.35	3.60	2.80	3.50	3.25	3.15	3.50
Chemical costs					$.00/Lb solids				
Liquid phenolic resin	25	30	30	25	29	25	29	25	25
Emulsified wax	19	19	19	19	19	19	19	19	19
Energy costs									
Electricity	4.5	1.0	2.0	2.21	1.8	3.0	1.8	1.99	3.0
($.00/kWh)									
Oil	20.90	12.50	15.50	13.80	17.50	16.50	14.50	11.80	16.50
$/6 Million Btu									
Land costs					$/Acre				
	1,000	8,000	3,500	700	1,500	1,000	2,500	1,200	1,000

[1] 30% added to cover fringe benefits.

234

Table 4.--ELECTRICAL REQUIREMENTS

Raw Material	Press Size			
	4' x 8'	4' x 16'	4' x 24'	8' x 24'
	Plant Capacity (MMSF, 1/2" per annum)			
	37.5	75	112.5	150
	- - - - - - $\underline{kWh/ft^3\ finished\ product}$ - - - - - -			
NORTHERN SITES				
100% flakes	188	–	–	–
40% flakes; 60% chips	255	193	166	172
40% logs; 60% chips	288	210	193	204.
SOUTHERN SITES				
100% flakes	184	–	–	–
40% flakes; 60% chips	251	192	162	171
40% logs; 60% chips	280	205	189	199

APPENDIX D.--PRODUCTION COSTS FOR FOUR SIZES OF STRUCTURAL FLAKEBOARD FACILITIES AT 16 U.S. LOCATIONS

Production costs are expressed in the equation form of:

$$PC = a + bX$$

where,

PC is production cost ($/MSF, 1/2 in.),
a is production cost excluding wood cost ($/MSF, 1/2 in.), and
b is coefficient of wood cost per ODT (X) for calculating wood cost per MSF, 1/2 in.

Production costs have been computed for three different assumptions related to selling expense allowances:

1. Low selling expense allowance, which assumes a 2 percent cash discount and annual product promotional costs, for the first three years of operation, equal to $.50/MSF of the rated annual output of the facility considered.

2. Average selling expense allowance which assumes a 2 percent cash discount and 5 percent for miscellaneous product promotional and selling expenses.

3. High selling expense allowance which assumes full 5, 3, and 2 percent functional discounting allowances.

Corresponding a and b values for production costs are given in the following tables.

Table 1.--PRODUCTION COSTS FOR STRUCTURAL FLAKEBOARD AT NORTHERN SITES, SUBJECT TO 2% DISCOUNT

Northern Sites	Raw Material	Plant Capacity (MMSF, 1/2" per annum)							
		37.5		75		112.5		150	
		a	b	a	b	a	b	a	b
St. Anthony, Id.	100% flakes	156.20	1.105						
	40% flakes; 60% chips	169.60	1.105	131.10	1.094	118.60	1.091	117.10	1.069
	40% logs; 60% chips	193.40	1.168	147.60	1.157	132.50	1.154	125.50	1.131
Virginia, Minn.	100% flakes	162.20	1.108						
	40% flakes; 60% chips	176.70	1.108	136.10	1.097	123.00	1.094	121.60	1.073
	40% logs; 60% chips	201.80	1.173	153.70	1.162	138.30	1.159	134.30	1.136
Western Mont.	100% flakes	159.30	1.105						
	40% flakes; 60% chips	173.00	1.105	132.70	1.094	120.30	1.091	119.00	1.070
	40% logs; 60% chips	197.40	1.168	150.20	1.157	135.20	1.154	131.70	1.131
La Grande, Oreg.	100% flakes	161.40	1.132						
	40% flakes; 60% chips	175.30	1.132	135.10	1.120	122.40	1.117	121.00	1.096
	40% logs; 60% chips	199.90	1.198	152.50	1.184	137.20	1.181	133.50	1.159
Medford, Oreg.	100% flakes	157.70	1.128						
	40% flakes; 60% chips	171.00	1.128	132.00	1.116	119.70	1.113	118.20	1.092
	40% logs; 60% chips	194.50	1.191	148.60	1.178	133.80	1.175	130.10	1.153
Southern Vt.	100% flakes	176.50	1.285						
	40% flakes; 60% chips	190.90	1.285	152.40	1.272	139.70	1.267	137.90	1.244
	40% logs; 60% chips	213.90	1.358	167.80	1.345	152.80	1.341	148.80	1.315
Longview, Wash.	100% flakes	159.10	1.154						
	40% flakes; 60% chips	172.60	1.154	133.30	1.143	121.00	1.139	119.50	1.117
	40% logs; 60% chips	196.20	1.218	150.00	1.206	135.10	1.202	131.50	1.179
Northern W. Va.	100% flakes	166.10	1.284						
	40% flakes; 60% chips	183.40	1.284	145.90	1.271	133.30	1.266	132.40	1.243
	40% logs; 60% chips	206.00	1.357	160.40	1.343	145.90	1.339	143.00	1.314
Laramie, Wyo.	100% flakes	153.10	1.101						
	40% flakes; 60% chips	166.00	1.101	129.00	1.091	117.20	1.087	116.00	1.066
	40% logs; 60% chips	188.90	1.163	145.00	1.152	130.90	1.148	127.50	1.125

Table 2.--<u>PRODUCTION COSTS FOR STRUCTURAL FLAKEBOARD AT NORTHERN SITES, SUBJECT TO 5 AND 2% DISCOUNTS</u>

Northern Sites	Raw Material	Plant Capacity (MMSF, 1/2" per annum)							
		37.5		75		112.5		150	
		a	b	a	b	a	b	a	b
St. Anthony, Id.	100% flakes	164.20	1.164						
	40% flakes; 60% chips	178.40	1.164	137.80	1.153	124.60	1.149	123.10	1.127
	40% logs; 60% chips	203.50	1.231	155.20	1.219	139.30	1.216	131.90	1.191
Virginia, Minn.	100% flakes	170.50	1.168						
	40% flakes; 60% chips	185.80	1.168	143.10	1.156	129.30	1.153	127.90	1.130
	40% logs; 60% chips	212.30	1.236	161.60	1.225	145.40	1.221	141.20	1.197
Western Mont.	100% flakes	167.60	1.164						
	40% flakes; 60% chips	181.90	1.164	139.50	1.153	126.50	1.150	125.00	1.127
	40% logs; 60% chips	207.60	1.231	157.90	1.220	142.10	1.216	138.40	1.192
La Grande, Oreg.	100% flakes	169.80	1.193						
	40% flakes; 60% chips	184.50	1.193	142.10	1.181	128.70	1.177	127.20	1.155
	40% logs; 60% chips	210.30	1.262	160.40	1.248	144.30	1.245	140.40	1.221
Medford, Oreg.	100% flakes	165.90	1.189						
	40% flakes; 60% chips	179.90	1.189	138.70	1.176	125.80	1.173	124.20	1.150
	40% logs; 60% chips	204.60	1.255	156.30	1.241	140.60	1.238	136.80	1.215
Southern Vt.	100% flakes	185.70	1.354						
	40% flakes; 60% chips	200.80	1.354	160.20	1.340	146.90	1.336	145.00	1.311
	40% logs; 60% chips	225.10	1.431	176.50	1.417	160.70	1.413	156.40	1.386
Longview, Wash.	100% flakes	167.30	1.216						
	40% flakes; 60% chips	181.50	1.216	140.20	1.204	127.10	1.200	125.60	1.177
	40% logs; 60% chips	206.40	1.284	157.80	1.271	142.00	1.267	138.20	1.242
Northern W. Va.	100% flakes	174.70	1.353						
	40% flakes; 60% chips	192.90	1.353	153.40	1.339	140.10	1.335	139.20	1.310
	40% logs; 60% chips	216.80	1.429	168.70	1.416	153.40	1.411	150.30	1.384
Laramie, Wyo.	100% flakes	161.00	1.160						
	40% flakes; 60% chips	174.60	1.160	135.60	1.149	123.20	1.146	121.90	1.123
	40% logs; 60% chips	198.70	1.225	152.50	1.214	137.60	1.210	134.00	1.186

Table 3.--PRODUCTION COSTS FOR STRUCTURAL FLAKEBOARD AT NORTHERN
SITES, SUBJECT TO 5, 3, AND 2% DISCOUNTS

Northern Sites	Raw Material	Plant Capacity (MMSF, 1/2" per annum)							
		37.5		75		112.5		150	
		a	b	a	b	a	b	a	b
St. Anthony, Id.	100% flakes	169.70	1.203						
	40% flakes; 60% chips	184.40	1.203	142.40	1.191	128.80	1.188	127.20	1.164
	40% logs; 60% chips	210.30	1.272	160.40	1.260	144.00	1.256	136.30	1.231
Virginia, Minn.	100% flakes	170.50	1.168						
	40% flakes; 60% chips	192.00	1.207	147.90	1.195	133.60	1.191	132.10	1.168
	40% logs; 60% chips	219.40	1.278	167.00	1.266	150.30	1.262	145.90	1.237
Western Mont.	100% flakes	173.20	1.203						
	40% flakes; 60% chips	188.00	1.203	144.10	1.191	130.70	1.188	129.20	1.165
	40% logs; 60% chips	214.60	1.272	163.20	1.260	146.90	1.257	143.00	1.231
La Grande, Oreg.	100% flakes	175.50	1.233						
	40% flakes; 60% chips	190.60	1.233	146.80	1.220	133.00	1.216	131.40	1.193
	40% logs; 60% chips	217.30	1.304	165.70	1.290	149.10	1.286	145.10	1.262
Medford, Oreg.	100% flakes	171.40	1.228						
	40% flakes; 60% chips	185.90	1.228	143.40	1.215	130.00	1.212	128.40	1.189
	40% logs; 60% chips	211.50	1.297	161.50	1.283	145.30	1.279	141.30	1.255
Southern Vt.	100% flakes	191.90	1.399						
	40% flakes; 60% chips	207.50	1.399	165.60	1.385	151.80	1.380	149.80	1.354
	40% logs; 60% chips	232.60	1.479	182.40	1.464	166.00	1.460	161.70	1.432
Longview, Wash.	100% flakes	172.90	1.256						
	40% flakes; 60% chips	187.60	1.256	144.90	1.245	131.40	1.240	129.80	1.217
	40% logs; 60% chips	213.30	1.327	163.00	1.314	146.80	1.309	142.80	1.284
Northern W. Va.	100% flakes	180.60	1.398						
	40% flakes; 60% chips	199.30	1.398	158.50	1.384	144.80	1.379	143.90	1.353
	40% logs; 60% chips	224.00	1.477	174.40	1.463	158.50	1.458	155.30	1.430
Laramie, Wyo.	100% flakes	166.40	1.199						
	40% flakes; 60% chips	180.40	1.199	140.10	1.188	127.30	1.184	126.00	1.161
	40% logs; 60% chips	205.30	1.266	157.60	1.254	142.20	1.250	138.50	1.225

Table 4.--PRODUCTION COSTS FOR STRUCTURAL FLAKEBOARD AT SOUTHERN SITES, SUBJECT TO 2% DISCOUNT

Southern Sites	Raw Material	Plant Capacity (MMSF, 1/2" per annum)							
		37.5		75		112.5		150	
		a	b	a	b	a	b	a	b
rcata, Calif.	100% flakes	144.90	1.159						
	40% flakes; 60% chips	158.80	1.159	120.10	1.148	107.00	1.144	104.10	1.122
	40% logs; 60% chips	181.70	1.227	134.50	1.214	118.50	1.210	114.50	1.187
outhcentral Ga.	100% flakes	141.80	1.284						
	40% flakes; 60% chips	155.50	1.284	119.70	1.271	107.30	1.266	104.70	1.243
	40% logs; 60% chips	175.20	1.357	130.90	1.343	115.80	1.339	112.10	1.314
ornith, Miss.	100% flakes	142.70	1.282						
	40% flakes; 60% chips	155.80	1.282	122.20	1.269	110.40	1.265	107.90	1.242
	40% logs; 60% chips	174.80	1.355	132.70	1.341	118.40	1.337	114.80	1.312
outhern Mo.	100% flakes	144.30	1.280						
	40% flakes; 60% chips	158.30	1.280	121.70	1.267	109.20	1.263	106.60	1.239
	40% logs; 60% chips	178.10	1.351	133.10	1.338	118.10	1.334	114.40	1.308
ak Ridge, Tenn.	100% flakes	142.90	1.284						
	40% flakes; 60% chips	156.10	1.284	122.10	1.271	110.30	1.266	108.00	1.243
	40% logs; 60% chips	175.50	1.357	133.00	1.343	118.60	1.339	115.20	1.314
outheastern Tenn.	100% flakes	138.70	1.289						
	40% flakes; 60% chips	152.20	1.289	116.70	1.276	104.50	1.272	102.00	1.248
	40% logs; 60% chips	173.70	1.362	129.60	1.349	114.70	1.343	111.00	1.319
ast Texas	100% flakes	144.10	1.280						
	40% flakes; 60% chips	158.20	1.280	121.60	1.276	109.10	1.263	106.50	1.239
	40% logs; 60% chips	177.90	1.351	133.00	1.338	117.90	1.333	114.30	1.308

239

Table 5.—PRODUCTION COSTS FOR STRUCTURAL FLAKEBOARD AT SOUTHERN SITES, SUBJECT TO 5 AND 2% DISCOUNTS

Southern Sites	Raw Material	Plant Capacity (MMSF, 1/2" per annum)							
		37.5		75		112.5		150	
		a	b	a	b	a	b	a	b
Arcata, Calif.	100% flakes	152.30	1.221						
	40% flakes; 60% chips	167.00	1.221	126.20	1.210	112.40	1.205	109.40	1.183
	40% logs; 60% chips	191.10	1.292	141.40	1.280	124.60	1.275	120.30	1.251
Southcentral Ga.	100% flakes	149.10	1.353						
	40% flakes; 60% chips	163.50	1.353	125.80	1.339	112.70	1.335	110.00	1.310
	40% logs; 60% chips	184.30	1.429	137.60	1.416	121.70	1.411	117.80	1.384
Cornith, Miss.	100% flakes	150.10	1.351						
	40% flakes; 60% chips	163.90	1.351	128.50	1.338	116.00	1.333	113.40	1.308
	40% logs; 60% chips	183.90	1.427	139.50	1.413	124.40	1.409	120.60	1.382
Southern Mo.	100% flakes	151.70	1.349						
	40% flakes; 60% chips	166.50	1.349	127.90	1.335	114.80	1.331	112.00	1.306
	40% logs; 60% chips	187.40	1.424	139.90	1.410	124.10	1.405	120.20	1.379
Oak Ridge, Tenn.	100% flakes	150.30	1.353						
	40% flakes; 60% chips	164.20	1.353	128.40	1.339	115.90	1.335	113.50	1.310
	40% logs; 60% chips	184.70	1.429	139.90	1.416	124.70	1.411	121.10	1.384
Southeastern Tenn.	100% flakes	145.80	1.358						
	40% flakes; 60% chips	160.00	1.358	122.70	1.345	109.80	1.340	107.10	1.315
	40% logs; 60% chips	182.70	1.435	136.30	1.421	120.60	1.416	116.70	1.390
East Texas	100% flakes	151.60	1.349						
	40% flakes; 60% chips	166.30	1.349	127.80	1.335	114.70	1.331	111.90	1.306
	40% logs; 60% chips	187.20	1.423	139.80	1.410	124.00	1.405	120.10	1.378

Table 6.--PRODUCTION COSTS FOR STRUCTURAL FLAKEBOARD AT SOUTHERN
SITES, SUBJECT TO 5, 3, AND 2% DISCOUNTS

Southern Sites	Raw Material	Plant Capacity (MMSF, 1/2" per annum)							
		37.5		75		112.5		150	
		a	b	a	b	a	b	a	b
rcata, Calif.	100% flakes	157.40	1.262						
	40% flakes; 60% chips	172.60	1.262	130.40	1.250	116.20	1.246	113.10	1.222
	40% logs; 60% chips	197.50	1.336	146.10	1.322	128.70	1.318	124.30	1.292
outhcentral Ga.	100% flakes	154.10	1.398						
	40% flakes; 60% chips	169.00	1.398	130.00	1.384	116.50	1.379	113.70	1.353
	40% logs; 60% chips	190.50	1.477	142.10	1.463	125.80	1.458	121.70	1.430
ornith, Miss.	100% flakes	155.10	1.396						
	40% flakes; 60% chips	169.30	1.396	132.70	1.382	119.90	1.378	117.20	1.352
	40% logs; 60% chips	190.00	1.475	144.20	1.461	128.60	1.456	124.60	1.428
outhern Mo.	100% flakes	156.80	1.394						
	40% flakes; 60% chips	172.10	1.394	132.20	1.380	118.60	1.375	115.80	1.350
	40% logs; 60% chips	193.60	1.471	144.60	1.457	128.20	1.452	124.20	1.425
ak Ridge, Tenn.	100% flakes	155.30	1.398						
	40% flakes; 60% chips	169.60	1.398	132.70	1.384	119.80	1.379	117.30	1.353
	40% logs; 60% chips	190.80	1.477	144.50	1.463	128.80	1.458	125.10	1.430
outheastern Tenn.	100% flakes	150.70	1.404						
	40% flakes; 60% chips	165.40	1.404	126.80	1.390	113.40	1.385	110.70	1.359
	40% logs; 60% chips	188.80	1.483	140.80	1.469	124.60	1.463	120.60	1.436
ast Texas	100% flakes	156.60	1.394						
	40% flakes; 60% chips	171.90	1.394	132.10	1.380	118.50	1.375	115.70	1.349
	40% logs; 60% chips	193.40	1.471	144.50	1.457	128.10	1.452	124.10	1.424